

LIFE - HISTORIES OF MICHIGAN HALIPLIDAE
(COLEOPTERA)

RESPIRATION OF THE HALIPLIDAE
(COLEOPTERA)

**CONTRIBUTION TO THE BIOLOGY
OF THE HALIPLIDAE**
(COLEOPTERA)

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THE immature stages of the Haliplidae occurring in this country have received but little study. In fact, instars of only three species have been described. This work was done by Matheson (1912, pp. 178-191), and his observations on two haliplids were confirmed by Wilson (1923, pp. 271-275). This comprises the life-histories known for the different species of Haliplidae that are found in America. A general survey of the family was begun in the fall of 1924 and has been continued until the present time. Primarily, the Michigan haliplids, especially those occurring in the vicinity of Ann Arbor and the University of Michigan Biological Station at Douglas Lake, Michigan, have been studied. All the species known for Michigan have been reared by the author and the various stages examined in detail. On the following pages will be found descriptions of the different instars for *Peltodytes lengi* Rbts., *Peltodytes sexmaculatus* Rbts., *Peltodytes edentulus* Lec., *Haliplus immaculicollis* Harr., *Haliplus cribrarius* Lec. and *Haliplus triopsis* Say. Descriptions of the egg and first instar, however, are lacking for each of the last two species.

TECHNIQUE

The living stages were killed in boiling water and passed through the lower percentages of alcohol to 85 per cent. The material was prepared for study by first clearing it in hot 10 per cent caustic potash, washing it in water, and then transferring it to 85 per cent alcohol in Syracuse watch-glasses. In the drawings, general outlines and the locations of various structures were made with the aid of a camera lucida. The first and third larval instars were em-

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phasized in the descriptions and only those structures of the second are mentioned that were different from the other two. Whenever possible, repetition was avoided. Permanent mounts were made of the dissected parts and deposited in the author's collection. A series of total alcoholic specimens were deposited in the Museum of the University of Michigan, the zoölogical collection of the Department of Zoölogy of the University of Michigan and the author's collections.

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PELTODYTES LENGI Roberts

EGG (Pl. XLVII, Figs. 1-4)

Size. — Length, 0.415–0.483 mm., average of 10 eggs 0.453 mm.; diameter, 0.231–0.289 mm., average of 10 eggs, 0.266 mm. Length increasing and diameter decreasing with development.

Shape. — Oval, with small, projecting plug (micropylar area) at anterior end. Chorion thin; superficially smooth, but under magnification faintly yet definitely reticulate; reticulation composed of polygonal units varying in shape and size; each reticulation unit in form of minute circular depression giving granular appearance to surface. Micropylar area circular; extending slightly beyond surface of chorion; composed of four to eight openings.

Color. — Yellowish-brown. Few days before hatching, six ocelli in one group, appearing on each side through the chorion as reddish-black spots.

LARVA

First Larval Instar (Pl. XLVII, Figs. 5-7)

Recently hatched larva. — Length of body, 0.65–0.80 mm., average of 10 specimens, 0.75 mm. Width of head, 0.38–0.48 mm.,

average of 10 specimens, 0.42 mm. Body broadest at head; thorax and abdomen tapering posteriorad. Body color milky-white; tips of mandibles yellowish-brown; ocelli dark brown. Appearance differing markedly from older larvae in much greater relative length of legs and dorsal projections. Principal internal structures evident through translucent integument.

Five-day larva. — Size rapidly increasing to second moult. Body length including caudal projections, 1.68–2.31 mm., average of 10 specimens, 2.11 mm.; width of head, 0.42–0.502 mm., average of 10 specimens, 0.46 mm. Length of terminal segment, 0.168–0.21 mm., average of 10 specimens, 0.186 mm. Length of caudal projections, 0.504–0.756 mm., average of 10 specimens, 0.672 mm. Body broadest at head; thorax and abdomen tapering slightly posteriorad. Body surface, exclusive of projections and setae, very smooth.

Head capsule. — Epicranial suture very indistinct; junction of arms at posterior border of head; stem very short. Setae moderately long, situated on each side as follows: two on epistomal margin, outer one longest; one near median line in region of frons; three above antenna; two adjacent to arm of epicranial suture; one above and one posterior to ocular stalk; five on ocellar protuberance; one ventrad to antenna; two on region of submentum.

Ocelli. — Six globular ocelli in circle on strong lateral protuberance; color dark brown. Size and shape not uniform.

Antenna (Pl. XLVII, Fig. 5). — Three-segmented; first segment about as wide as long; second more than three times as long as first, widest at middle; third about as long as second, but about half as wide. Second with very short appendage on inner, distal margin. Two setae on distal end of third segment, one about as long as third segment and one very short.

Mandible (Pl. XLVII, Fig. 6). — About as wide as long; strong apical tooth-like structure larger on left than right; two setae on external margin.

Maxilla. — Twice as long as wide; with three setae, two-segmented palpus, second the longer; group of setae on cephalo-median margin.

Labium. — Rounded on free margin; two-segmented palpus; no setae.

Prothorax. — Longest of body segments; smooth; weakly chitinized. Four two-segmented projections, two lateral and two dorsal; very long and slender; length more than twice the width of body; first segment shorter; covered with granular projections; second segment smooth. Lateral projections with one long seta distal from first segment, and one spine near base. Eight strong setae dorso-cephalad; four setae further posteriorad.

Meso- and metathorax. — Projections and appearance same as in prothorax. Two setae between lateral and dorsal projections on each side, inner one longer; one seta at base of each dorsal projection.

Abdomen. — Nine-segmented; dorsal aspect of first eight segments similar except in decrease in width caudad; smooth; weakly chitinized. Each segment with four long two-segmented projections, similar to those on thorax with exception that first segment of lateral projections lacks long terminal seta. Two small setae on each side between lateral and dorsal projections; one at base of each dorsal projection. Ninth segment terminating in two long cercus-like projections; each caudal projection with four lateral and one terminal setae; equal in length to last three abdominal segments.

Ventral aspect of segments. — Thoracic segments without setae except four on cephalic margin of prothorax. First eight segments of abdomen with four setae on ventral aspect of each and two on each side in region of pleurum. Ninth segment with prominent rounded protuberance with anal opening near median line.

Legs. — First thoracic leg very short; half as long as third; fitted for grasping; consisting of coxa, trochanter, femur, tibia, tarsus and claw. Number and arrangement of setae similar to those found in third instar. Second and third thoracic legs similar except third slightly longer. Number and arrangement of setae similar to those in third instar.

Spiracles. — Absent. Tracheae extending into the long dorsal and lateral projections.

Second Larval Instar (Pl. XLVIII, Fig. 8)

Body length, including caudal projections, 2.8–4.2 mm., average of 10 specimens, 3.36 mm. Width of head, 0.56–0.58 mm., average of 10 specimens, 0.57 mm. Length of terminal segment, 0.21–0.34 mm., average of 10 specimens, 0.29 mm. Length of caudal projections, 1.05–1.5 mm., average of 10 specimens, 1.26 mm. Larva more closely resembling third larval instar. Body very smooth except for projections and setae.

Antenna. — Three-segmented, but third segment composed of two terminal, parallel, diminutive, subequal projections.

Mandibles. — External margin with three setae.

Dorsal aspect of prothorax. — Four long projections, of nine segments each, over 2 mm. long. First segment of each projection with two prominent spines. Six prominent dorsal setae near cephalic margin.

Dorsal aspect of meso- and metathorax. — Similar to prothorax except cephalic setae lacking and only one spine on first segment of projection. (The length of this spine proves to be a useful character in separating species. In this species the length of this spine is equal to the thickness of projection which bears it. Its length is 0.021 mm.)

Abdomen. — Nine segments. Dorsal aspect of first six segments with four long projections similar to those of thorax. Number of segments in projections 8–10. Dorsal aspect of seventh and eighth segments each with two long dorsal projections and two short, lateral, stub-like projections. Ninth segment with two long projections directed posteriorad; projection composed of six segments, each with one seta on latero-distal margin; one seta on distal end of terminal segment. First segments of caudal projection with seven scattered setae. Ventral aspect of thoracic segment with seta-bearing projection near base of coxa of each pair of legs (not shown in Fig. 8). First eight segments of abdomen with six ventral setae, median two the largest; also five setae on each side of lateral aspect, in two groups of two (anterior) and three (posterior). No spiracles; trachea extending into long dorsal and lateral projections to tip.

Third Larval Instar (Pl. XLIX, Fig. 9; Pl. L, Figs. 10-17, 19)

Body length including caudal projections, 9.1-11.3 mm., average of 10 specimens, 10.5 mm. Width of head, 0.71-0.75 mm., average of 10 specimens, 0.73 mm. Length of terminal segment, 0.38-0.42 mm., average of 10 specimens, 0.40 mm. Length of caudal projections, 4.83-5.1 mm., average of 10 specimens, 4.96 mm. Color of body light yellow. Head light brown. Tips of mandibles dark brown. Ocelli blackish.

Head capsule (Pl. L, Fig. 10). — Trapezoidal; prognathous; slightly flattened above; more globular below. Arms of epicranial suture convergent behind; suture very short. Capsule interspersed with short setae inserted upon small protuberances.

Ocelli (Pl. L, Fig. 11). — Six, arranged in circle upon prominent lateral protuberance.

Antenna (Pl. L, Fig. 12). — Laterad; cephalad to ocelli; on protuberance; four segments; filamentous; light amber in color. Scape slightly wider than long; with few sense pits on distal margin. Pedicel one fourth longer than scape, but little narrower. Two-segmented flagellum about one and one-half times as long as scape and pedicel combined; first segment about three times as long as second; bobbin-shaped; greatest diameter proximal; small sense pore on disto-lateral margin; second segment composed of two diminutive, parallel, terminal, subequal parts; inner part shorter, conical; outer part rectangular, bearing seta at apex; seta slightly longer than segment.

Mandibles (Pl. L, Fig. 13). — Asymmetrical; fairly prominent with rather sharp beak-like tip; three fourths as wide as long; outer margin convex with six rather large setae, proximal one shortest; two sense pores on dorso-lateral aspect. Tooth-like projection on each inner margin. Orifice of suction canal irregular; on ventral side of beak. Condyle small; triangular; short; no neck. Left mandible slightly larger than right; left beak distinctly larger than right.

Maxilla (Pl. L, Fig. 14). — Cardo rectangular with one seta on cephalo-lateral margin. Stipes about as long as wide with five setae in two transverse rows; palpus two-segmented; second seg-

ment about as long as first; first with two setae and ring of sense pores on distal margin; distal margin of stipes with pointed projection covered with fine setae; two knife-like projections on cephalo-mesal margin.

Labium (Pl. L, Fig. 15). — Short; rectangular; with two setae on mentum area; palpus two-segmented; first segment very short with one seta; second segment blunt.

Prothorax. — Longest segment; great number of short setigerous tubercles on cephalic region; bearing six long segmented projections on dorsal aspect, two lateral, two dorsal and two dorso-lateral. Lateral and dorsal projections with about fourteen segments. Two prominent and several smaller spines on first segment of lateral and dorsal projections. First three segments of lateral and dorsal projections with whorl of tiny angular processes around distal margin; remaining segments smooth. Dorso-lateral projections with about twelve segments.

Dorsal aspect of meso- and metathorax. — Mesothorax and metathorax similar; each with four long projections of 16–18 segments, first segment with two prominent spines. (These spines prove to be useful characters in separating species. In this species the length of the spine is equal to the thickness of projection which bears it. Length, 0.042 mm.) First three segments of projections have whorl of tiny angular processes on distal margin. One seta between dorsal and lateral projection.

Dorsal aspect of first seven abdominal segments. — With four long 16–18 segmented projections. Projections similar to those of thorax except one seta on first segment of lateral projection. Eighth abdominal segment with two long dorsal projections and two lateral stub-like processes. Ninth abdominal segment sub-cylindrical terminating in two cylindrical, divergent, about 8–12 segmented projections, about as long as whole abdomen. (The number of segments in the terminal projections varies widely even in the pair of the same individual.) Basal segment of terminal projection long, with many setigerous tubercles largely on proximal half; each succeeding segment except terminal one with one seta, usually laterad; segments gradually tapering to thread-like terminations.

Ventral aspect of prothorax. — Without setae. Mesothorax and metathorax with two setigerous tubercles on median line.

Ventral aspect of abdomen. — With 8–10 setigerous tubercles on each segment, arranged in transverse rows; also several small setae scattered irregularly.

Lateral aspect of each abdominal segment. — With three prominent setae. Spiracles present; one pair on mesothorax and one pair on each of first seven abdominal segments.

First pair of thoracic legs (Pl. L, Figs. 16–17). — Rather short; prehensile; composed of coxa, trochanter, femur, tibia, tarsus and claw. Coxa longest, tapering distad; distal margin incurved on dorsal side to allow bending back of trochanter; about as long as wide; several prominent setae on distal and proximal margins. Trochanter not quite as long as coxa, but twice as long as wide; convex on ventral side, concave on dorsal side; transverse row of sense pores mesad; one seta on dorsal face, five on ventral face, distal one longest. Femur one and one-half times as long as trochanter and about half as wide as long; four setae on dorsal face; several others scattered on both sides. Tibia slightly shorter than femur; ventro-distal margin expanding into thumb-like process; distal surface of latter serrated; one seta on each side at base of process, one on ventral aspect near apex, and one strong seta on apex; serrations or processes large at base and becoming smaller distad. Tarsus about two thirds as long as tibia and two thirds as wide; few setae on distal margin, and one group on disto-ventral aspect. Claw as long as tarsus; rather sharp, with setigerous tubercle on ventral face; one seta just proximad of tubercle.

Second and third thoracic legs. — Similar; about twice as long as first; proportions of segments to each other about same as for first; distribution of setae similar to that of first legs; tibiae without distal process. Adapted for walking.

PUPA (Pl. L, Figs. 22–23)

Typical exarate pupa. Total length, 3.45–3.60 mm., average of 5 specimens, 3.57 mm. Width including wings, 2.05–2.12 mm., average of 5 specimens, 2.1 mm. Length of pronotum, 0.72–0.82 mm., average of 5 specimens, 0.8 mm. Width of pronotum, 1.21–

1.28 mm., average of 5 specimens, 1.26 mm. Shape, oval, distinctly enlarged at mid-section. Body color, light cream. Eyes, reddish-black. Setae of different lengths, mostly inserted upon short tubercles. Ocelli, six; arranged in two compact rows just within lateral margin of compound eyes. Head with one short seta slightly above each antenna and two on vertex. Antennae diagonally across eyes. Pronotum longest; with ten long setae and two short ones, arranged as follows: six long ones on cephalic margin and four long ones on caudal margin; two short ones on caudal margin. Mesonotum and metanotum with four short setae each. Abdomen with nine segments; transverse section decreasing rapidly caudad. First six segments each with two long setae and four short ones. Seventh segment with four short setae; eighth with six, and ninth with twelve. First and second legs folded upon themselves at femuro-tibial joint; one seta at this joint. Third legs straight, projecting slightly beyond abdomen. Tube-like spiracles on second, third and fourth segments.

PELTODYTES SEXMACULATUS Roberts

EGG

The eggs of *P. sexmaculatus* Rbts., *P. lengi* Rbts. and *P. edentulus* Lec. are so nearly identical in appearance that the author was unable to detect any structural features by means of which these three could be separated, in spite of the fact that all structural features were critically studied. Therefore, the description given for the egg of *P. lengi* Rbts. will serve for that of *P. sexmaculatus* Rbts.

LARVA

First Larval Instar

Here again the first larval instars of *P. sexmaculatus* Rbts., *P. lengi* Rbts. and *P. edentulus* Lec. are so nearly identical in appearance that the author was unable to find differences in structures by which these three could be separated. The description given for the first larval instar of *P. lengi* Rbts. will serve for that of *P. sexmaculatus* Rbts.

Second Larval Instar

The only observed difference in the larval structures of this instar from those of *Peltodytes lengi* Rbts. and *P. edentulus* Lec. is in the length of the spine on the dorsal projections. It is much longer and more pointed than in the other two, the length being about one and one-third times the diameter of the projection.

Third Larval Instar

The only observed difference in the larval structures of this instar when compared with that of *Peltodytes lengi* Rbts. and *P. edentulus* Lec. is the same feature already described above under the heading "Second larval instar."

PUPA

Structural features of the pupae of *P. sexmaculatus* Rbts., *P. lengi* Rbts. and *P. edentulus* Lec. were identical, as far as the author was able to determine. Therefore, the description given for *P. lengi* Rbts. will serve for that of *P. sexmaculatus* Rbts.

PELTODYTES EDENTULUS Leconte

EGG

The description given for the egg of *P. lengi* Rbts. will serve for that of *P. edentulus* Lec., since no differences could be observed between eggs of these two species.

LARVA

First Larval Instar

Since the first larval instars of *P. sexmaculatus* Rbts. are so nearly identical to those of *P. lengi* Rbts., it is not necessary to give a description of this instar.

Second Larval Instar

The only structure observed to be different in this instar from those of *Peltodytes lengi* Rbts. and *P. sexmaculatus* Rbts. is in the length of spine on the dorsal projections. It is much shorter than in the other two, the length being about two thirds the thickness of the projection.

Third Larval Instar

This instar was found to differ from *Peltodytes lengi* Rbts. and *P. sexmaculatus* Rbts. only in the same feature already described above under the heading "Second larval instar."

PUPA

Structural features of the pupae of *Peltodytes edentulus* Lec., *P. lengi* Rbts. and *P. sexmaculatus* Rbts. were identical as far as the author was able to determine. Therefore the description given for *P. lengi* Rbts. will serve for that of *P. edentulus* Rbts.

HALIPLUS IMMACULICOLLIS Harris

EGG (Pl. LI, Fig. 24)

Size. — Length, 0.338–0.386 mm., average of 10 eggs, 0.368 mm.; diameter, 0.212–0.231 mm.; average of 10 eggs, 0.224 mm.

Shape. — Similar to the eggs of the described species of the genus *Peltodytes*.

Color. — Whitish. Six ocelli in one group; appearing on each side through chorion as reddish-black spots.

LARVA

First Larval Instar (Pl. LI, Figs. 25–27)

Recently hatched larva. — Length of body, 1.4–1.8 mm., average of 5 specimens, 1.6 mm. Width of head, 0.164–0.172 mm., average of 5 specimens, 0.168 mm. Head slightly narrower than thorax. Body segments, 13, tapering gradually posteriorad. Color milky-white with exception of yellowish-brown mandible tips and dark brown ocelli. Body very compact and resembling first larval instar of *Peltodytes lengi* Rbts., *P. sexmaculatus* Rbts. and *P. edentulus* Lec. Integument translucent, principal internal structures showing through.

Older larva. — Body length including caudal projections, 2.3–3.12 mm., average of 5 specimens 2.86 mm.; width of head, 0.19–0.23 mm., average of 5 specimens, 0.21 mm. Length of terminal segment, 0.35–0.45 mm., average of 5 specimens, 0.42 mm. Length of caudal projections, 0.25–0.32 mm., average of 5 specimens, 0.29

mm. Body much longer and resembling later instars of same species.

Head capsule. — With very indistinct epicranial suture; arms of suture uniting at caudal edge of head; stem of suture very short. Both dorsal and ventral aspects of surface with small round tubercles. Setae usually on rather prominent projections arranged on each side as follows: two behind ocellar area and two laterad to epicranial suture; two small ones near median line in region of frons; several small setae on cephalic margin of head; one below antenna and two on region of submentum.

Ocelli. — Six; globular; one slightly cephalo-ventrad to antenna; remaining five in two vertical rows, cephalic row with two and caudal with three.

Antenna (Pl. LI, Fig. 26). — With four segments; similar to that of mature larva except outer part of fourth segment and terminal seta are longer proportionately.

Mandible. — Slightly longer than wide with one seta on external margin; apical tooth strong.

Maxilla. — Twice as long as wide. Palpus, three-segmented; third segment longest. One group of setae on anterior margin.

Labium. — Rounded on free margins; palpus, two-segmented; no setae.

Prothorax. — Longest segment. Dorsal aspect with twenty setigerous tubercles, arranged in six rows, two dorsal rows of three each, two lateral rows of five each, and two dorso-lateral rows of two each.

Meso- and metathorax. — Similar, with ten setigerous tubercles situated as follows: two dorsal rows of two each, caudal one longest; lateral row of two each, caudal one with the very long seta and dorso-lateral one very short.

Abdomen. — Ten segments. Dorsal aspect of first seven segments similar; each with eight setigerous tubercles; two dorsal rows with two each, caudal one longest; one laterad, and one dorso-laterad; setae on lateral ones longer than others. Eighth and ninth segments with six setigerous tubercles; two dorsal rows with two each, one seta laterad. Setigerous tubercles of each body segment on plate more heavily chitinized than rest of body

wall; plate also granulose. Tenth segment (Pl. LI, Fig. 27) slightly longer than others, terminating in two projections, each with one lateral and one terminal seta; surface also granulose.

Ventral aspect of each thoracic segment. — With one setigerous tubercle laterad to coxa. Ventral aspect of first nine abdominal segments with four rather prominent setae in transverse row; one group of setae on each side. Anal protuberances not very prominent; consisting of one and two lateral lobes.

Legs. — Similar in shape and arrangement of setae to those of mature larva. Spiracles absent.

Second Larval Instar (Pl. LI, Figs. 28-29)

Larva very similar to third instar and quite different from first. Body length including caudal projections, 3.36-4.41 mm., average of 5 specimens, 4.25 mm. Width of head, 0.294-0.336 mm., average of 5 specimens, 0.315 mm. Length of terminal segments, 0.84-0.105 mm., average of 5 specimens, 0.92 mm. Length of caudal projections, 0.25-0.336 mm., average of 5 specimens, 0.28 mm. Conspicuous change in number, form and arrangement of setigerous tubercles on dorsal and ventral aspect of body segments. Dorsal aspect of prothorax with six longitudinal rows of tubercles; also several on cephalic margin; tubercles of lateral rows numerous, those of dorso-lateral rows fewer; two long setae on caudal margin and three on cephalic margin. Mesothorax and metathorax with same number of rows, but with fewer tubercles; 6-8 tubercles in lateral row, 3-4 in dorsal, and 2-3 in dorso-lateral rows; one long seta in lateral row. Nine abdominal segments like mesothorax and metathorax; number of tubercles variable, but always more on lateral row; tenth segment greatly elongated, with numerous setigerous tubercles. Each caudal projection with seven lateral setae and one terminal seta. Ventral aspect of abdominal segments with five setigerous tubercles arranged in inverted V-shaped figure; also four others with shorter tubercles and longer setae. Lateral aspects with four setae on each side, two closely grouped together.

Third Larval Instar (Pl. LII, Figs. 30-39)

Body length including caudal projections, 7.42-7.85 mm., average of 5 specimens, 7.62 mm. Width of head, 0.30-0.42 mm.,

average of 5 specimens, 0.35 mm. Length of terminal segment, 1.72–1.85 mm., average of 5 specimens, 1.8 mm. Length of caudal projections, 0.38–0.42 mm., average of 5 specimens, 0.40 mm. Body with bluish-black, mid-dorsal stripe; head light brown; tips of mandibles dark brown; ocelli blackish.

Head capsule. — With indistinct epicranial suture; arms of suture convergent near caudal margin of capsule; stem very short. Four prominent setigerous tubercles on capsule; two posteriorad to ocellar area; two laterad to epicranial suture. Several setae scattered over capsule.

Ocelli. — Six; five grouped together in imperfect semicircle posteriorad to antenna. Sixth, ventro-cephalad to antenna.

Antenna (Pl. LII, Fig. 32). — Dorso-cephalad to ocellar area; four segments, filiform. Scape slightly wider than long; few sense pores on distal margin. Pedicel one fourth longer than scape, but a little narrower. Flagellum two-segmented; one and one-half times longer than scape and pedicel combined; first segment longest, more than four times the second, bobbin-shaped, greatest diameter slightly distad of middle; one long seta on latero-distal margin. Terminal segment composed of two diminutive, parallel, subequal parts; inner part shorter, conical; outer part rectangular, bearing seta at apex; seta about twice as long as segment.

Mandible (Pl. LII, Fig. 33). — About as long as wide; strongly elliptical in cross-section; outer face convex with four rather stout setae; proximal one shortest; strong apical tooth. Orifice of suction canal on ventral side of tooth. Inner face with sharply pointed projection; condyle round, with short neck. Tooth of left mandible slightly longer than right.

Maxilla (Pl. LII, Fig. 34). — With simple cardo; triangular; one seta on lateral aspect. Stipes twice as long as wide; rectangular. Palpus three-segmented; third segment as long as first two; second with three setae. Distal margin with many setae. Disto-mesal margin with notch and two stout setae.

Labium (Pl. LII, Fig. 35). — Rounded; two setae on ventral aspect. Palpus two-segmented, second slightly longer than first. Distal margin with four setae.

Dorsal aspect of prothorax. — Unlike other segments. Protho-

rax longest; with many more setigerous tubercles; cephalic area thickly covered. Shallow depressions on each side of meson. Setigerous tubercles in six rows, becoming more distinct on caudal region. Terminal tubercles branched.

Dorsal aspect of meso- and metathorax. — Very similar in appearance. Setigerous tubercles in six rows. One elongate seta in each of four median rows. Lateral margin rounded.

Dorsal aspect of first seven abdominal segments. — Similar. Setigerous tubercles in six rows; arrangement and number variable; rows tending to coalesce cephalad. Eighth segment with only four rows and ninth with but two. Tenth segment (Pl. LII, Fig. 36) greatly prolonged; caudal projections with six lateral setae and one terminal; whole segment, except projections, covered with small setigerous tubercles.

Ventral aspect of thorax. — With two setigerous tubercles laterad to each coxa. Coxa bounded cephalad with serrated chitinized plate.

Ventral aspect of abdomen. — With chitinized plate covered with setigerous tubercles.

Lateral aspect of each abdominal segment. — With one seta. Eight pairs of spiracles; one pair on mesothorax and seven pairs on the first seven abdominal segments.

First pair of thoracic legs (Pl. LII, Fig. 37-38). — Fitted for grasping, consisting of coxa, trochanter, femur, tibia, tarsus and claw. Coxa broadly inserted; decreased in size distad; thickest segment of leg; about twice as long as wide; few angular short spines on ventral face; several scattered smaller setae; one larger seta on disto-cephalic face. Trochanter, convexo-concave; about two thirds-as long as coxa; with ring of sense pores near middle; one seta on dorsal face and several on ventral face, very long one near distal margin. Femur short, slightly longer than trochanter, but wider; several angular spines on ventral side; three setae on dorsal margin; two stout setae on ventro-cephalic face; few scattered setae on lateral areas. Tibia about three fourths as long as femur, with prolongation on disto-ventral face terminating in two stout tooth-like setae and few angular spines; two setae on disto-cephalic and caudal aspect, one on proximo-dorsal face and several angu-

lar spines near middle of dorsal face. Tarsus about one half as long as tibia, with small spines on disto-ventral aspect; several setae on distal margin and two on dorsal margin. Claw, one and one-half times as long as tarsus; tooth-like projection on ventral face.

Second and third pair of thoracic legs. — Similar to first except about twice as long and prolongation absent on tibia. Adapted for walking.

PUPA (Pl. LII, Fig. 39)

Total length, 2.07–2.12 mm., average of 5 specimens, 2.1 mm. Width including wings, 1.24–1.28 mm., average of 5 specimens, 1.26 mm. Length of pronotum, 0.41–0.44 mm., average of 5 specimens, 0.42 mm. Width of pronotum, 0.61–0.65 mm., average of 5 specimens, 0.63 mm. Shape oval; distinctly enlarged at mid-section. Color, light cream, except reddish-black eyes. All setae of practically same length; inserted upon low tubercles. Ocelli six; grouped in straight line; laterad to compound eyes. Head with two rather short setae slightly above antenna and two on vertex. Antennae diagonally across eyes. Pronotum longest; with twelve setae, six on cephalic margin and six on caudal margin. Mesonotum and metanotum each with six setae. Abdomen with nine segments; tapering rapidly posteriorad. Each of first seven segments with eight setae all about same length and arranged in transverse row. Eighth segment with six setae and ninth with none. First and second legs folded at femuro-tibial joint; short seta on this joint. Third legs straight and extend slightly beyond abdomen. Tube-like spiracles on second, third and fourth segments.

HALIPLUS CRIBRARIUS Le Conte

Descriptions of the egg and first larval instar are lacking for this species, since the author was unable to secure them. The other stages, however, were obtained by collecting larvae of second instar and rearing them to the adult stage. The exuviae were saved and compared with the preserved material.

LARVA

Second Larval Instar (Pl. LIII, Fig. 40)

Body length including caudal projections, 4.3-5.6 mm.; average of 5 specimens, 4.8 mm. Width of head, 0.48-0.54 mm.; average of 5 specimens, 0.52 mm. Length of terminal segment, 0.91-1.05 mm.; average of 5 specimens, 0.95 mm. Length of caudal projections, 0.054-0.126 mm.; average of 5 specimens, 0.082 mm. Larva differing from third larval instar in number, form, and arrangement of setigerous tubercles on dorsal and ventral aspect of body segments. Dorsal aspect of prothorax with four, many-branched projections posteriorad, two lateral and two dorsal ones. Each branch terminating with one seta. One very long seta inserted on low tubercles on each lateral projection, one between lateral and dorsal projections, and one cephalad to each lateral projection. About thirty setigerous tubercles on cephalic region. Mesothorax and metathorax similar to prothorax except lacking cephalic setigerous tubercles. About fifteen setigerous tubercles on each lateral projection and about ten on each dorsal projection. First nine abdominal segments similar to mesothorax and metathorax. Tenth abdominal segment greatly elongated, with numerous setigerous tubercles. Each caudal projection with four setigerous tubercles, and one terminal seta. Ventral aspect of abdominal segments with six setigerous tubercles in posterior transverse line. Lateral aspect of first eight abdominal segments with two closely grouped together setae on each side.

Third Larval Instar (Pl. LIV, Figs. 42-50)

Body length including caudal projections, 11.3-12.5 mm.; average of 10 specimens, 12 mm. Width of head, 0.63-0.67 mm.; average of 10 specimens, 0.65 mm. Length of terminal segment, 3.36-3.62 mm.; average of 10 specimens, 3.48 mm. Length of caudal projections, 0.16-0.18 mm.; average of 10 specimens, 0.17 mm. Body subcylindrical; tapering posteriorad from thorax to tip of prolonged caudal segment. Body amber color; head slightly darker; tips of mandibles dark brown; ocelli blackish.

Head capsule (Pl. LIV, Fig. 43). — Rectangular in dorsal out-

line; slightly wider than long. Prognathous. Epicranial suture very indistinct. Granular elevations covering entire capsule. Few scattered setae; one prominent, hook-shaped setigerous tubercle posteriorad to each ocellar area.

Ocelli (Pl. LIV, Fig. 44). — Six; grouped together in two vertical rows; unequal; slightly projecting.

Antenna (Pl. LIV, Fig. 45). — Dorso-cephalad to ocellar area; four-segmented; filiform. Scape slightly wider than long, few sense pores on distal margin. Pedicel one third longer than scape, but a little narrower. Flagellum, two-segmented; about twice as long as scape and pedicel combined; first segment more than four times longer than second, bobbin-shaped; one seta on latero-distal margin. Terminal segment composed of two, diminutive, parallel, subequal parts; inner part slightly longer, conical; outer part rectangular, bearing seta at apex; seta about as long as segment.

Mandibles. — Hook-shaped; about one fifth longer than wide; lateral margin convex. Two setae on lateral margin, proximal one shorter than distal one. Strong apical tooth. Orifice of suction canal on ventral side of tooth. Inner face with sharply pointed projection. Condyle round, with short neck. Tooth of left mandible slightly longer than right.

Maxilla (Pl. LIV, Fig. 46). — With cardo simple; free; subtriangular; one seta on ventro-lateral aspect. Stipes subtrapezoidal; large; about as long as wide; two parallel rows of setae on lateral margin; three in each row; group of both stout and fine setae on meso-distal margin, stout ones mesad to group. Maxillary palpus three-segmented; basal segment slightly wider than long, one seta on lateral margin; second segment about as long as basal, not quite so wide; with two setae; apical segment conical, one third longer than second, twice as long as wide, sensory organs on apex.

Labium (Pl. LIV, Fig. 47). — Rectangular, about two times wider than long; two setae on mentum area. Labial palpus of two segments, proximal segment as long as wide; distal segment conical, slightly longer than proximal segment, but narrower; four setae on distal margin of labium.

Prothorax. — About twice as wide as head, and twice as long; bears four long, stout, blunt pointed, horn-like processes. Dorsal

and lateral surface of processes densely covered with setigerous tubercles. Processes terminate with heavily chitinized point. Cephalic region of prothorax bearing numerous setigerous tubercles. Ten long, scattered setae on segment.

Dorsal aspect of meso- and metathorax. — Similar. Each segment with four horn-like processes, similar to those of prothorax. Three half-round protuberances on cephalic area, with fine angular spines. Each segment with six long setae.

Dorsal aspect of first nine abdominal segments. — Similar, except tapering posteriorad; number and arrangement of horn-like processes and long setae similar to mesothorax and metathorax. Tenth abdominal segment very long and tapering, covered with setigerous tubercles; end of segment bifid very short distance (one twentieth of total length); terminating with long, stout setae. One setigerous tubercle on each branch.

Ventral aspect of thorax. — With several setigerous tubercles; each coxa bounded cephalad with serrated chitinized plate.

Ventral aspect of first nine abdominal segments. — With chitinized plate covering about one half of surface of each segment. Each plate covered rather sparsely with setigerous tubercles. Similar to dorsal ones, but shorter. Eight pairs of spiracles, one pair on mesothorax, and rest on first seven abdominal segments on lateral aspect. One group of two setae on lateral aspect of first nine abdominal segments.

First pair of thoracic legs. — Coxa, one and one-half times longer than wide. Group of triangular granular elevations on proximo-ventral aspect. Several strong, scattered setae on all faces. Trochanter twice as long as wide; convexo-concave; ventral aspect with five long setae, and numerous short spines; median row of sensory pits. Femur more than twice as long as wide, club-shaped, with large end distal, covered with numerous short spines on ventral aspect. Several scattered setae on dorsal aspect. Tibia a little more than twice as long as wide, two thirds as long as femur; almost completely covered with rather regularly placed short spines; several long setae on distal margin. Tarsus three fourths as long as tibia; several short, subrectangular elevations on dorsal and ventral aspects; rather long and stout setae distad. Claw one

and one-fourth times as long as tarsus, tapering to rather sharp point; group of four spines on ventral margin.

Second and third pairs of thoracic legs. — Similar to first, except longer; adapted for walking.

PUPA

Total length, 3.72–3.81 mm.; average of 3 specimens, 3.78 mm. Width including wings, 1.64–1.69 mm.; average of 3 specimens, 1.68 mm. Length of pronotum, 1.04–1.06 mm.; average of 3 specimens, 1.05 mm. Width of pronotum, 0.83–0.85 mm.; average of 3 specimens, 0.84 mm. Size was the only observed difference between this species and *H. triopsis*. This species was somewhat larger. There are only six setae on the dorsal aspect of the first seven abdominal segments, as was true of *H. triopsis*.

HALIPLUS TRIOPSIS Say

Since the author was unable to obtain eggs of this species, the descriptions of the different stages that are given are based on a comparison of the exuviae of reared specimens and the preserved material that had been collected. No larvae of the first instar were taken in the field.

LARVA

Second Larval Instar (Pl. LIII, Fig. 41)

Body length including caudal projections, 5.46–5.88 mm.; average of 5 specimens, 5.67 mm. Width of head, 0.42–0.504 mm.; average of 5 specimens, 0.462 mm. Length of terminal segment, 1.47–1.76 mm.; average of 5 specimens, 1.67 mm. Length of caudal projections, 0.294–0.378 mm.; average of 5 specimens, 0.336 mm. Larva differing from third instar in number, form and arrangement of setigerous tubercles on dorsal and ventral aspect of body segments. Dorsal aspect of prothorax with four strong, many-branched setigerous tubercles posteriorad, two lateral and two dorsal ones; one long setigerous tubercle dorso-latero-posteriorad; several setigerous tubercles on cephalic region; twelve scattered long setae inserted on low tubercles. Mesothorax and metathorax similar to prothorax except lacking cephalic setigerous

tubercles; number of setigerous tubercles about thirty on each segment; four long setae inserted on low tubercles. First nine abdominal segments similar to mesothorax and metathorax. Tenth abdominal segment greatly elongated, with numerous setigerous tubercles. Each of caudal projections with four setigerous tubercles and one terminal seta. Ventral aspect of abdominal segments with six setigerous tubercles in posterior transverse line. Lateral aspects of first eight abdominal segments with two setae closely grouped on each side.

Third Larval Instar (Pl. LV, Figs. 51-59)

Body length including caudal projections, 5.88-13.44 mm.; average for 10 specimens, 12.6 mm. Width of head, 0.546-0.63 mm.; average for 10 specimens, 0.588 mm. Length of terminal segment, 3.57-3.99 mm.; average of 10 specimens, 3.78 mm. Length of caudal projections, 0.16-0.21 mm.; average of 10 specimens, 0.18 mm. Body subcylindrical, tapering caudad from thorax to tip of prolonged caudal segment. Setigerous tubercles on body; amber brown; rest of body cream yellow; head amber brown; tips of mandibles dark brown; ocelli blackish.

Head capsule (Pl. LV, Fig. 52). — Subrectangular in dorsal outline; slightly wider than long; prognathous. Epicranial suture very indistinct. Several scattered patches of granular elevations. Few dispersed setae, both long and short; one prominent, hook-shaped, setigerous tubercle on each side just caudad to ocellar area.

Ocelli (Pl. LV, Fig. 53). — Six; grouped together in two imperfect vertical rows posteriorad to antenna; unequal; each slightly protruding.

Antenna (Pl. LV, Fig. 54). — Cephalad to ocellar area; four segments; filiform; incurved. Scape slightly wider than long; few sense pores on distal margin. Pedicel one third longer than scape, but a little narrower. Flagellum two-segmented; more than twice as long as scape and pedicel combined; first segment longest, more than four times the second; bobbin-shaped; one seta on latero-distal margin. Terminal segment composed of two diminutive, parallel, subequal parts; inner part slightly longer, conical;

outer part rectangular, bearing seta at apex; seta slightly longer than segment.

Mandibles (Pl. LV, Fig. 55). — Hook-shaped; about one fourth longer than wide; lateral margin convex, with two setae. Strong apical tooth. Orifice of suction canal on ventral side of tooth elliptical. Inner face with three sharply pointed projections. Condyle round, with short neck. Tooth of left mandible slightly longer than right.

Maxilla (Pl. LV, Fig. 56). — With simple cardo; free; triangular; one seta on lateral aspect. Stipes subtrapezoidal; slightly longer than wide; seven unequal setae on latero-ventral aspect. Palpus three-segmented; second and third segments about equal; second with two setae; third with sensory pits on apex. Distal margin with many fine setae. Disto-mesal margin with two stout setae.

Labium (Pl. LV, Fig. 57). — Rounded; submentum area with two groups of six setae in each. Mentum with two setae. Palpus two-segmented, second slightly longer than first. Group of three setae at base of each palpus. Two groups of three each on distal margin.

Prothorax. — Unlike other segments; longest; almost entire surface covered with setigerous tubercles with six branched setigerous tubercles posteriorad. Shallow depression free from tubercles on each side of meson.

Dorsal aspect of meso- and metathorax. — Very similar in appearance. Setigerous tubercles covering entire surface, with six branched tubercles posteriorad.

Dorsal aspect of first seven abdominal segments. — Similar to mesothorax and metathorax. Eighth and ninth segments with only four branched setigerous tubercles. Tenth segment (Pl. LV, Fig. 58) greatly prolonged; covered with setigerous tubercles; bifid at terminal end. Each branch very short, about one nineteenth of total length; each with two setigerous tubercles, one seta on side and one terminal seta.

Ventral aspect of thorax. — With two setigerous tubercles laterad to each coxa. Coxa bounded cephalad with serrated chitinized plate.

Ventral aspect of abdomen. — With chitinized plate covered with setigerous tubercles.

Lateral aspect of each abdominal segment. — With two setae, grouped together on each side of first nine segments. Eight pairs of spiracles; one pair on mesothorax and seven pairs on the first seven abdominal segments.

First pair of thoracic legs (Pl. LV, Fig. 59). — Not fitted for grasping; consisting of coxa, trochanter, femur, tibia, tarsus and claw. Coxa largest segment; broadly inserted; decreased in size distad; more than twice as long as wide; few scattered setae. Trochanter convexo-concave; about half as long as coxa; with ring of sense pores near middle; one seta on dorsal face, and several on ventral and lateral faces. Femur stout, about as long as coxa; row of several setae on dorsal face, and many scattered setae and angular projections on ventral face. Tibia about two thirds as long as femur; convex dorsal and ventral margins; several stout setae on distal margin; group of short, angular projections on disto-ventral aspect. Tarsus slightly shorter than tibia; several setae on distal margin, and short angular projections on ventral and dorsal aspect. Claw slightly longer than tarsus; two long, and two short tooth-like projections on ventral margin.

Second and third pairs of thoracic legs. — Similar to first, except a little longer. Adapted for walking.

PUPA

Total length, 3.27–3.40 mm.; average of 3 specimens, 3.36 mm. Width including wings, 1.81–1.88 mm.; average of 3 specimens, 1.86 mm. Length of pronotum, 0.41–0.43 mm.; average of 3 specimens, 0.42 mm. Width of pronotum, 0.59–0.67 mm.; average of 3 specimens, 0.63 mm. Structural features of this species are the same as those of *H. immaculicollis* Harr., except for the number of setae on abdomen. In *H. immaculicollis* there are eight setae on the dorsal aspect of each of first seven abdominal segments, but in *H. triopsis* there are only six setae.

KEY FOR THE IDENTIFICATION OF THE IMMATURE STAGES OF HALIPLIDAE DESCRIBED IN THIS PAPER

EGGS

- Eggs laid singly *on* branches of aquatic plants; color yellow; over 0.4 mm. in length.....Genus *Peltodytes*
Eggs inserted singly *within* branches of aquatic plants; color white; under 0.4 mm. in length.....Genus *Haliphus*

LARVAE

- 1 (14) Body with numerous elongated, segmented projections; abdomen nine-segmented.....Genus *Peltodytes* 2
- 2 (3) Projections two-segmented; mandibles with 2 setae on lateral aspect; antenna three-segmented.....FIRST LARVAL INSTAR
(No specific difference among three species: *P. edentulus* Lec., *P. sexmaculatus* Rbts. and *P. lengi* Rbts.)
- 3 (2) Projections more than two-segmented; mandibles with more than two 2 setae on lateral aspect; antenna three-segmented or more.....4
- 4 (9) Projections eight- or nine-segmented; mandibles with 3 setae on lateral aspect; antenna three-segmented.....
SECOND LARVAL INSTAR 5
- 5 (8) Length of spine on dorsal projections not greater than diameter of projection.....6
- 6 (7) Length of spine on dorsal projections equal to about two thirds of diameter of projections.....*P. edentulus* Lec.
- 7 (6) Length of spine on dorsal projections about equal to diameter of projections.....*P. lengi* Rbts.
- 8 (5) Length of spine on dorsal projections equal to about one and one-third times diameter of projections.....*P. sexmaculatus* Rbts.
- 9 (4) Projections twelve to eighteen-segmented; mandibles with 6 setae on lateral aspect; antenna four-segmented.....
THIRD LARVAL INSTAR 10
- 10 (13) Length of spine on dorsal projections not greater than diameter of projections.....11
- 11 (12) Length of spine on dorsal projections equal to about two thirds of diameter of projections.....*P. edentulus* Lec.
- 12 (11) Length of spine on dorsal projections about equal to diameter of projections.....*P. lengi* Rbts.
- 13 (10) Length of spine on dorsal projections equal to about one and one-third times diameter of projections.....*P. sexmaculatus* Rbts.
- 14 (1) Body with numerous setigerous tubercles; abdomen ten-segmented.....Genus *Haliphus* 15
- 15 (20) Tibia of first thoracic legs with thumb-like prolongation on disto-ventral margin; adapted for grasping.....16
- 16 (17) Dorsal aspect of each segment of body with few setigerous tubercles; 8-10 on each of the first seven abdominal segments.....FIRST LARVAL INSTAR, *H. immaculicollis* Harr.

- 17 (16) Dorsal aspect of each segment of body with several setigerous tubercles; 30-100 or more on each of the first seven abdominal segments.....18
- 18 (19) Dorsal aspect of each segment of body with 30-35 setigerous tubercles on each of the first seven abdominal segments....
- SECOND LARVAL INSTAR, *H. immaculicollis* Harr.
- 19 (18) Dorsal aspect of each segment of body with over 100 setigerous tubercles on each of the first seven abdominal segments....
- THIRD LARVAL INSTAR, *H. immaculicollis* Harr.
- 20 (15) Tibia of first thoracic legs without thumb-like prolongation on disto-ventral margin; not adapted for grasping.....21
- 21 (24) Dorsal aspect of each segment of body with several setigerous tubercles; 10-20 on each of the first seven abdominal segments.....SECOND LARVAL INSTAR 22
- 22 (23) Dorsal aspect of each segment of body with four prominences bearing setigerous tubercles; 5-8 on each of the first seven abdominal segments.....*H. triopsis* Say
- 23 (22) Dorsal aspect of each segment of body with four prominences bearing setigerous tubercles; 10-12 on each of the first seven abdominal segments.....*H. cribrarius* Lec.
- 24 (21) Dorsal aspect of each segment of body with many setigerous tubercles; more than 60 on each of the first seven abdominal segments.....THIRD LARVAL INSTAR 25
- 25 (26) Dorsal aspect of each segment of body without any horn-like projections.....*H. triopsis* Say
- 26 (25) Dorsal aspect of each segment of body with four horn-like projections.....*H. cribrarius* Lec.

PUPA

- Setae unequal in length.....Genus *Peltodytes*
- Setae about equal in length.....Genus *Haliphus*

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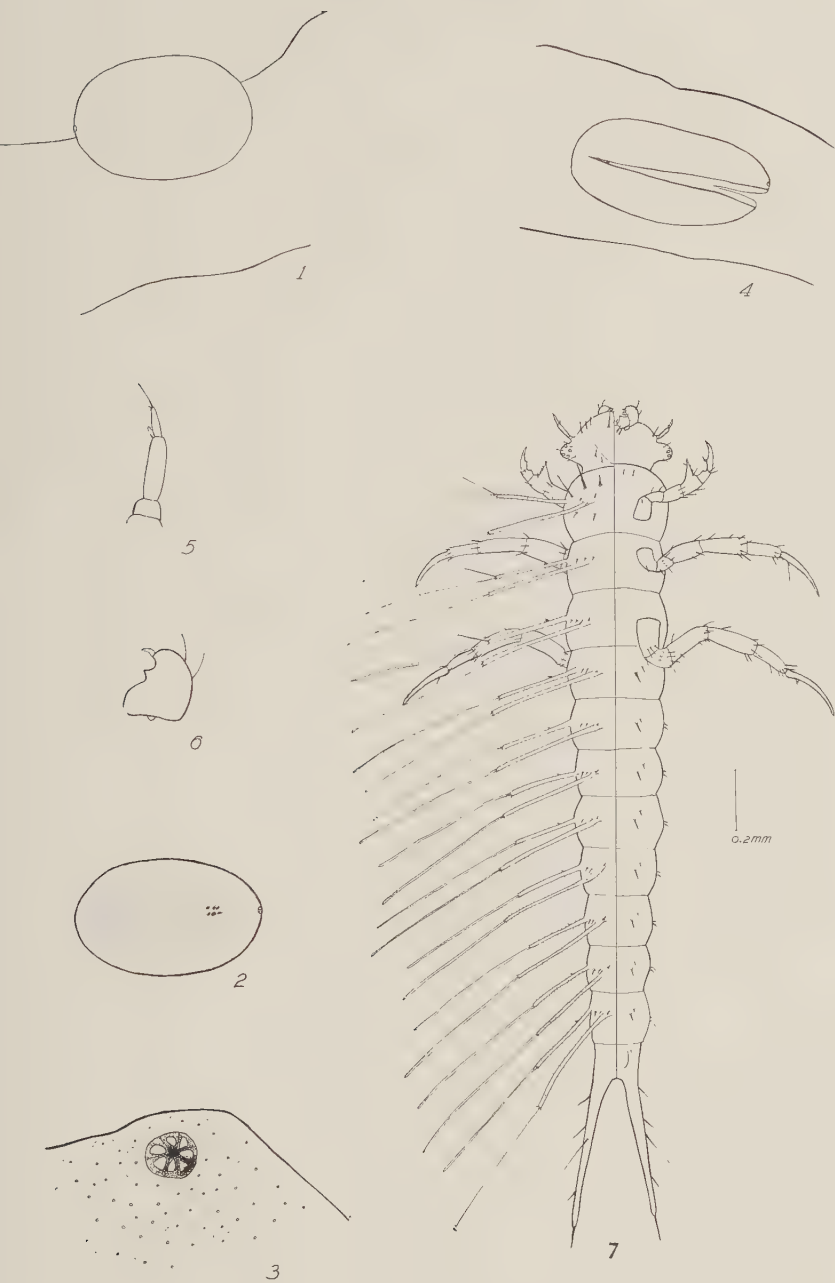
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EXPLANATION OF PLATE XLVII

Pellodytes lengi Roberts

- FIG. 1. Egg attached to branch of Ceratophyllum
- FIG. 2. Egg showing group of ocelli
- FIG. 3. Micropyle
- FIG. 4. Egg after hatching
- FIG. 5. Right antenna of first larval instar, dorsal view
- FIG. 6. Right mandible of first larval instar, dorsal view
- FIG. 7. First larval instar, dorsal side (to the left) and ventral side (to the right)

PLATE XLVII

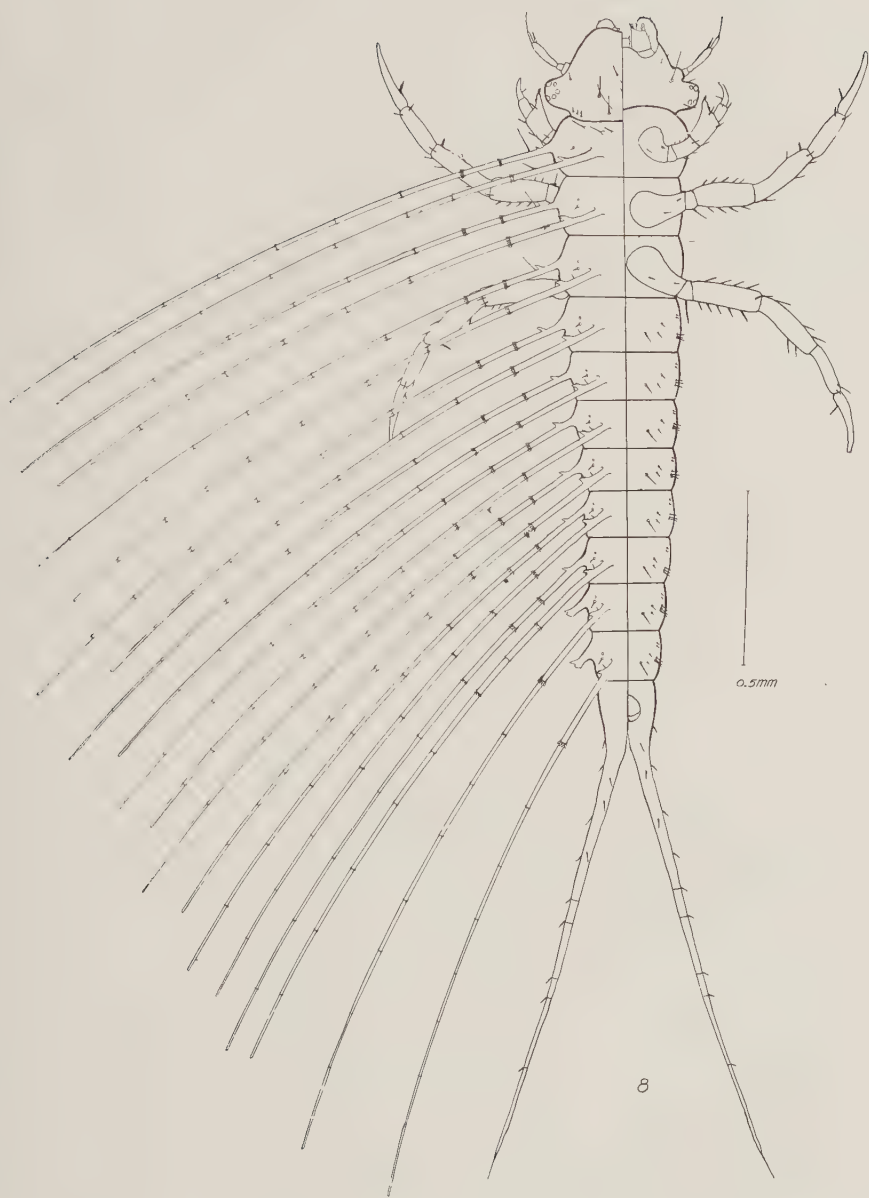


EXPLANATION OF PLATE XLVIII

Pellodytes lengi Roberts

FIG. 8. Second larval instar, dorsal side (to the left) and ventral side (to the right)

PLATE XLVIII

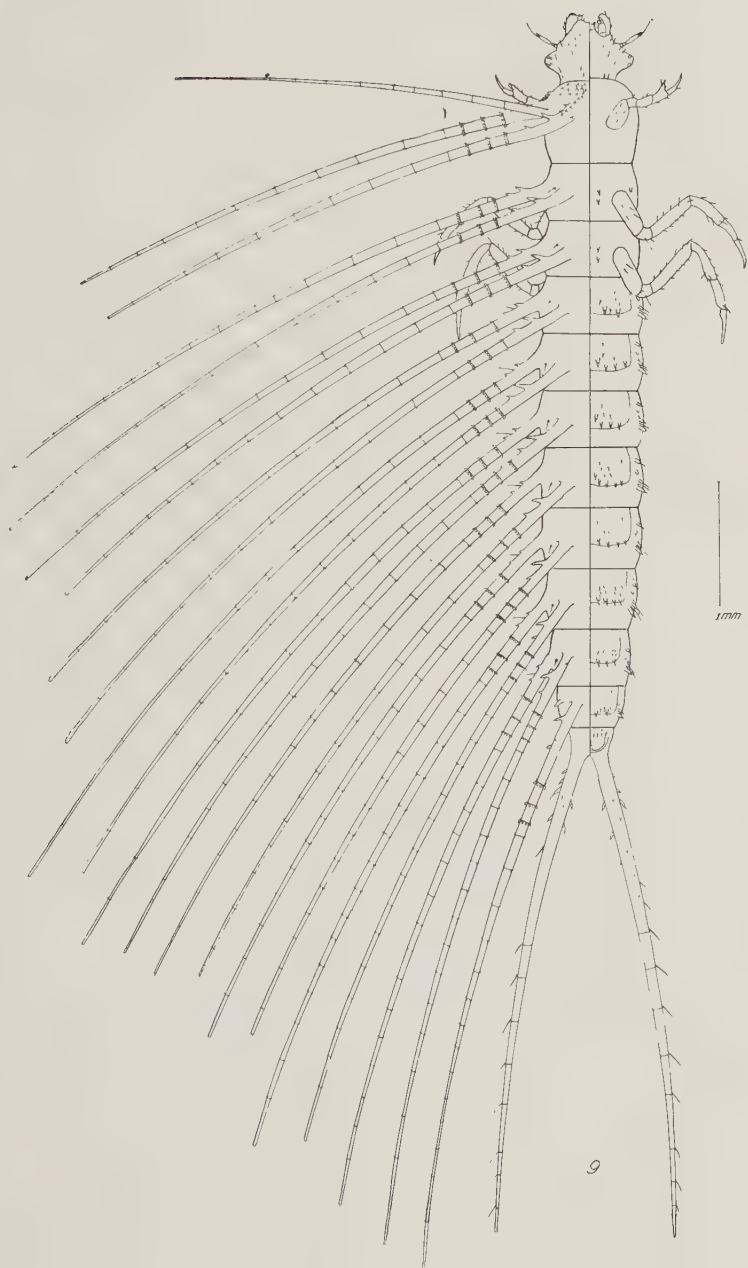


EXPLANATION OF PLATE XLIX

Peltodytes lengi Roberts

FIG. 9. Third larval instar, dorsal side (to the left) and ventral side (to the right)

PLATE XLIX



EXPLANATION OF PLATE L

Peltodytes lengi Roberts (except Figs. 18 and 20)

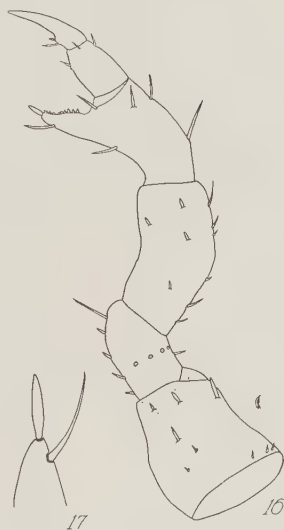
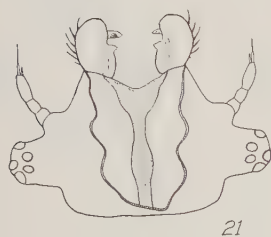
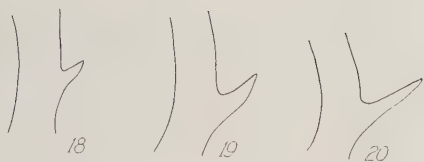
Third larval instar

- FIG. 10. Head capsule of *P. lengi*, dorsal side (to the left) and ventral side (to the right)
- FIG. 11. Head capsule of *P. lengi*, lateral view showing ocelli
- FIG. 12. Right antenna of *P. lengi*, dorsal view
- FIG. 13. Right and left mandibles of *P. lengi*, ventral view
- FIG. 14. Right maxilla of *P. lengi*, ventral view
- FIG. 15. Labium of *P. lengi*, ventral view
- FIG. 16. First thoracic leg of *P. lengi*, right
- FIG. 17. Prolongation of tibia, first thoracic leg of *P. lengi*, ventral view
- FIG. 18. Spine on dorsal projection of *P. edentulus*
- FIG. 19. Spine on dorsal projection of *P. lengi*
- FIG. 20. Spine on dorsal projection of *P. sexmaculatus*
- FIG. 21. Head capsule of *P. lengi* showing suction canal of mandibles

Pupa

- FIG. 22. Pupa of *P. lengi*, ventral view
- FIG. 23. Pupa of *P. lengi*, lateral view

PLATE L



EXPLANATION OF PLATE LI

Haliphus immaculicollis Harris

FIG. 24. Egg inserted in branch of Ceratophyllum

First larval instar

FIG. 25. First larval instar, dorsal side (to the left) and ventral side (to the right)

FIG. 26. Right antenna of first larval instar, dorsal view

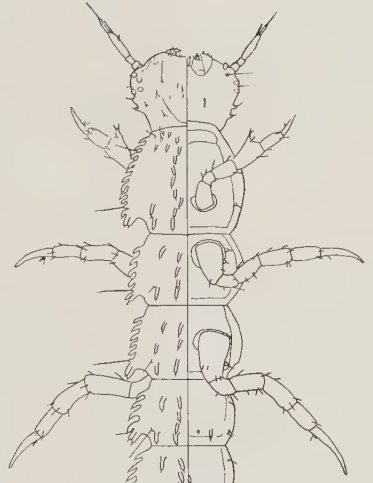
FIG. 27. Caudal segment of first larval instar, dorsal view

Second larval instar

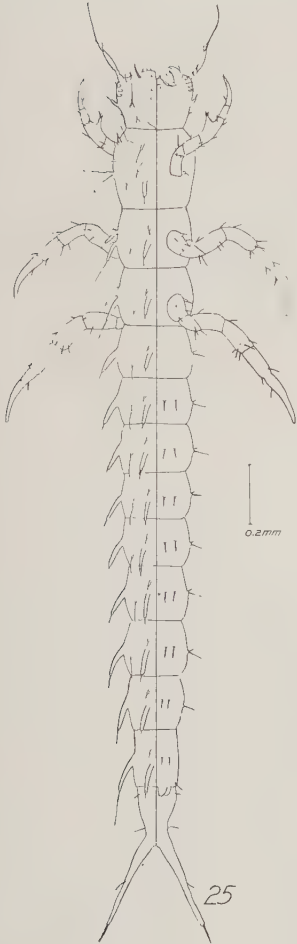
FIG. 28. Second larval instar, dorsal side (to the left) and ventral side (to the right)

FIG. 29. Right antenna of second larval instar, dorsal view

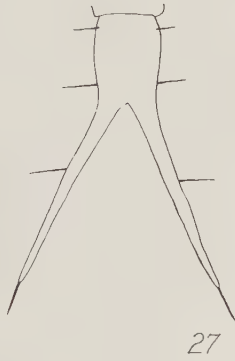
PLATE LI



0.2mm



0.2mm

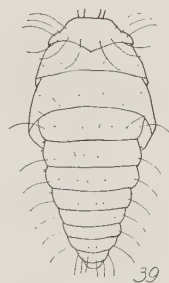
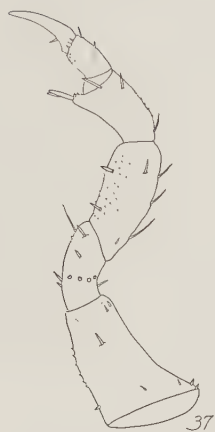
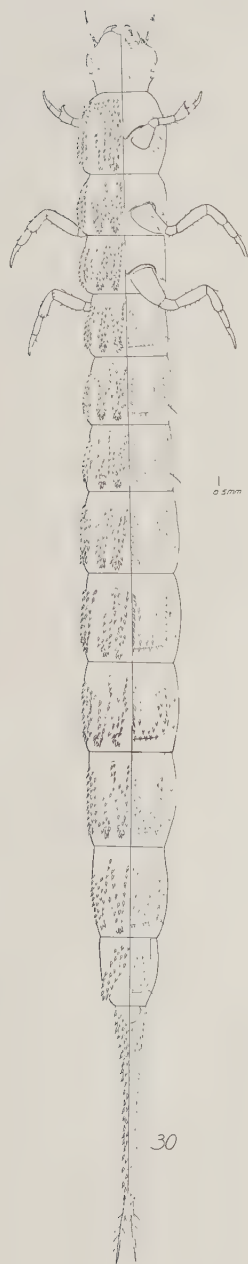


EXPLANATION OF PLATE LII

Haliplus immaculicollis Harris

- FIG. 30. Third larval instar, dorsal side (to the left) and ventral side (to the right)
- FIG. 31. Head capsule of third larval instar, lateral view
- FIG. 32. Left antenna of third larval instar, dorsal view
- FIG. 33. Right mandible of third larval instar, ventral view
- FIG. 34. Right maxilla of third larval instar, ventral view
- FIG. 35. Labium, ventral view
- FIG. 36. Caudal segment of third larval instar, dorsal view
- FIG. 37. First thoracic leg of third larval instar, right
- FIG. 38. Prolongation of tibia, first thoracic leg, third larval instar, ventral view
- FIG. 39. Pupa, dorsal view

PLATE LII

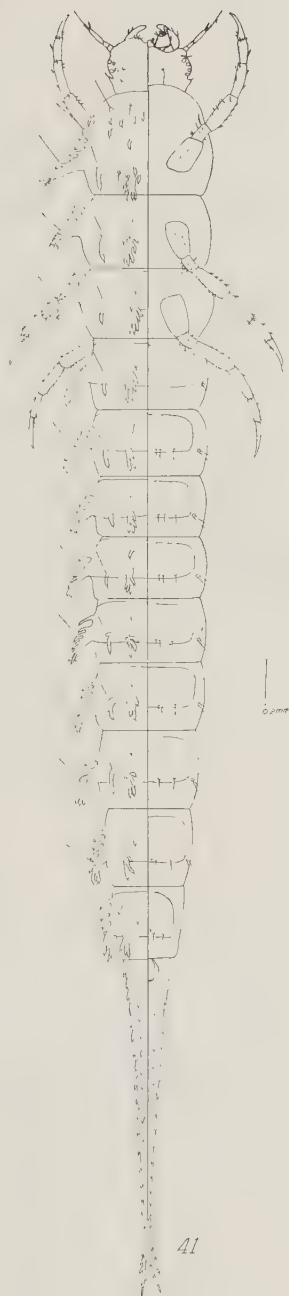
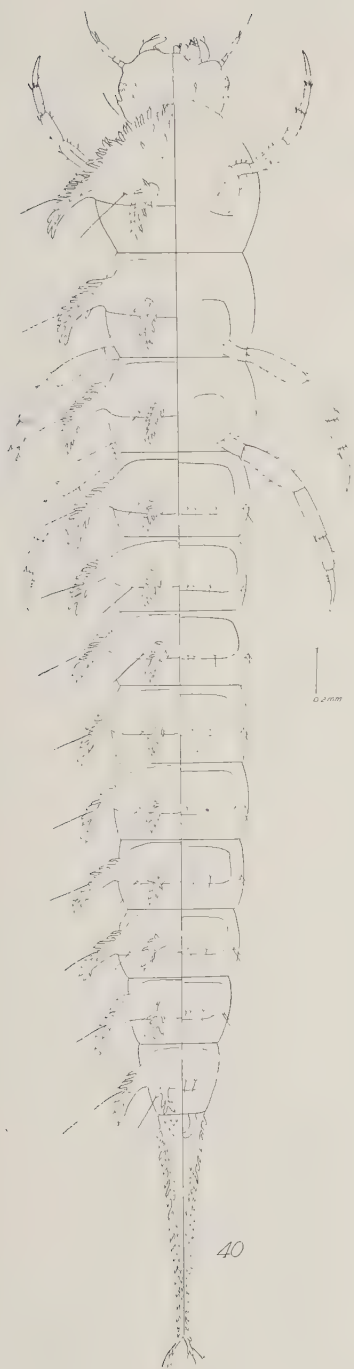


EXPLANATION OF PLATE LIII

FIG. 40. Second larval instar of *H. cribrarius*, dorsal side (to the left) and ventral side (to the right)

FIG. 41. Second larval instar of *H. triopsis*, dorsal side (to the left) and ventral side (to the right)

PLATE LIII

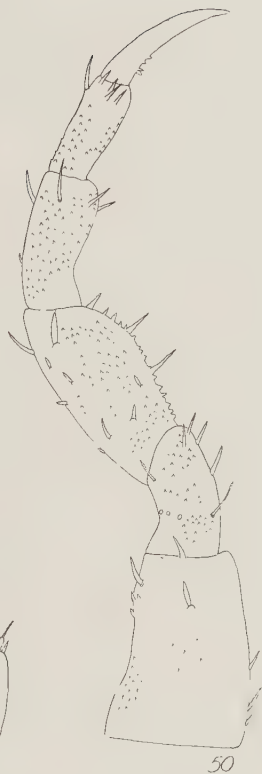
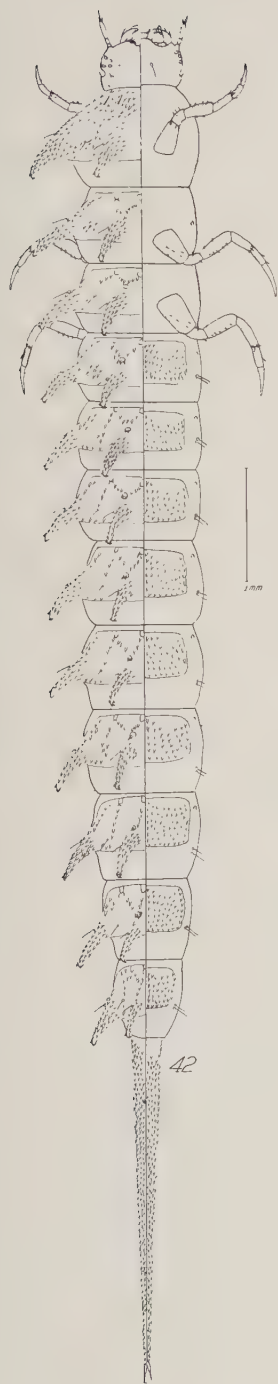


EXPLANATION OF PLATE LIV

Haliplus cribrarius Le Conte

- FIG. 42. Third larval instar, dorsal side (to the left) and ventral side (to the right)
- FIG. 43. Head capsule of the third larval instar, dorsal side (to the left) and ventral side (to the right)
- FIG. 44. Head capsule of third larval instar, lateral view
- FIG. 45. Left antenna of third larval instar, dorsal view
- FIG. 46. Right maxilla of third larval instar, ventral view
- FIG. 47. Labium of third larval instar, ventral view
- FIG. 48. Horn-like process of third larval instar, lateral view
- FIG. 49. Terminal portion of caudal projection, third larval instar
- FIG. 50. First thoracic leg of third larval instar, right

PLATE LIV

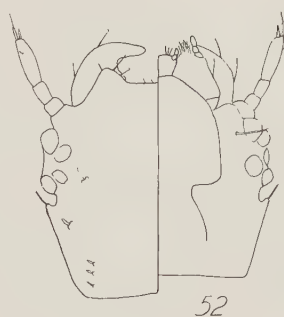
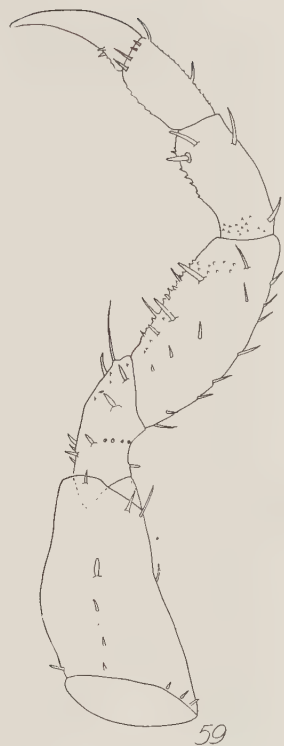
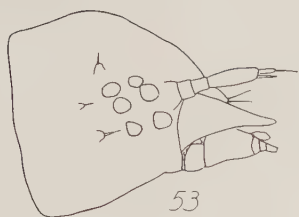


EXPLANATION OF PLATE LV

Haliplus triopsis Say

- FIG. 51. Third larval instar, dorsal side (to the left) and ventral side (to the right)
- FIG. 52. Head capsule of third larval instar, dorsal side (to the left) and ventral side (to the right)
- FIG. 53. Head capsule of third larval instar, lateral view
- FIG. 54. Left antenna of third larval instar, dorsal view
- FIG. 55. Right mandible of third larval instar, ventral view
- FIG. 56. Right maxilla of third larval instar, ventral view
- FIG. 57. Labium of third larval instar, ventral view
- FIG. 58. Terminal portion of caudal projection of third larval instar
- FIG. 59. Third thoracic leg of the third larval instar, right

PLATE LV



RESPIRATION OF THE HALIPLIDAE (COLEOPTERA) *

JENNINGS R. HICKMAN

INSECTS that live in water are noted for their different methods of securing oxygen. Since the haliplids are primarily aquatic animals, it is of interest to know how they have solved this problem. In fact, several investigators have been concerned with this problem as related to the imagoes, but each has arrived at a different explanation. Matheson (1912, p. 181) concluded that these beetles obtain their air supply by way of the posterior coxal plates — a method quite different from that of the closely allied forms. He thought it was impossible for them to take in air by the tip of the abdomen because the elytra are held firmly in place by special knoblike structures. He failed, however, to observe the fact that they can extend the pygidium far past the tip and at the same time not open the elytra. Brocher (1912, p. 178) announced that these insects take in air in the same manner as do the Dytiscidae. Later on, by means of some experiments and some observations with a magnifying glass, he (1922, pp. 7–17) attempted to prove that his former statement was correct and the view of Matheson wrong. He proposed the explanation that the air store which is noticeable between the posterior coxal plates and the abdomen came from the air store that is above the abdomen and under the elytra, and was hydrostatic only in function. Then Falkenström (1928, p. 19) gave an entirely new explanation of the mechanism of respiration and the function of the air store. He stated that under certain conditions the haliplids can take in air as do the Dytiscidae, but that generally they receive enough oxygen from the water by diffusion. The surface of the bubble which is present in the posterior coxal cavity serves as a diffusion membrane. He arrived at

* Contribution from the Zoölogical Laboratory of the University of Michigan.

this conclusion after he was unable to see the beetles, under normal conditions, come to the surface of the water to renew the air supply. After I had finished my own investigation, Beier (1929, pp. 204-209) published his work on *Haliphus wehncke* Gerh. He is inclined to agree with Brocher's explanation, although he gave no experimental evidence for thinking so. He thought that the important function of the coxal air store was to allow carbon dioxide to escape from the tracheal system.

With these views in mind, I attempted to analyze the method of respiration. Many experiments were performed to prove or disprove the views stated above and to add others if necessary. The investigation has been directed to answer three questions: (1) Where do the beetles obtain enough oxygen to support life? (2) What is the mechanism for obtaining the oxygen? (3) What is the function of the air stores?

The author wishes to express his indebtedness to Professor Paul S. Welch, under whose direction this study was made.

SOURCE OF OXYGEN

Some aquatic insects obtain their oxygen from that which has been dissolved in water while others take it directly from the atmosphere. According to the work of other investigators, there is a disagreement as to what group the haliplids belong to. In order to settle this question, the beetles were subjected to the requirements of both groups and conclusions were drawn from the results.

Prolonged submergence experiments

First, the beetles were tested to see whether they could live when they were allowed access only to the dissolved oxygen in the water. The following apparatus (Fig. 41) was devised for this investigation. Two eight-gallon rectangular aquaria (*a*, *a'*) were almost filled with cistern water and placed side by side, one of which was about six inches higher than the other. A test tube (*b*) with a pin hole in the bottom and an open glass arm sealed to the test tube about two inches from bottom was inverted in the lower aquarium. The arm was connected to a glass tube (*c*) which

extended to the bottom of the upper aquarium. Another glass tube led from the bottom of the lower aquarium to the top of the upper aquarium. To the lower end of this tube was connected a glass funnel (d). Air was bubbled into the glass funnel and as it passed over into the upper aquarium it carried some water along with it. This maintained the level higher in the upper aquarium than in the lower, and so the water was siphoned back into the test tube and out by way of the pin hole. The test tube contained a wire screen (f) suspended so that the beetles could

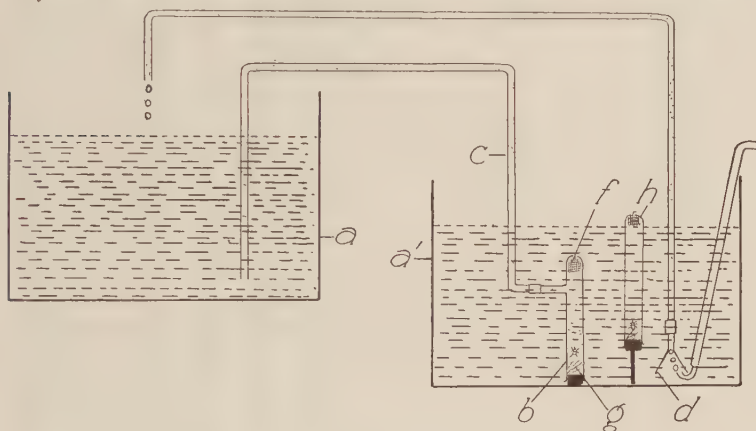


FIG 41. Prolonged submergence apparatus

hold on to it and crawl out of the current. Algae (g) fastened to the bottom served as a food supply. The beetles were placed in the test tube and allowed to become adjusted before the experiment was started. Then they were submerged. The purpose of the current at the top was to carry away any gas bubbles that might be formed from either the water or the plants. Controls (h) were maintained under the same conditions, except that the insects were allowed to get air at the surface. Minimum and maximum temperatures were recorded. In every case the experimental beetles died in a few days, while the controls lived for weeks. The accompanying chart (Fig. 42) gives the results at the low temperatures of 4 to 8 degrees. It can be seen that,

though the submerged beetles lived from 3 to 7 days, all the controls lived for 36 days, after which the experiments were discontinued. As a precaution to make sure that the beetles were dead, their positions were noted to see whether they moved after a one-

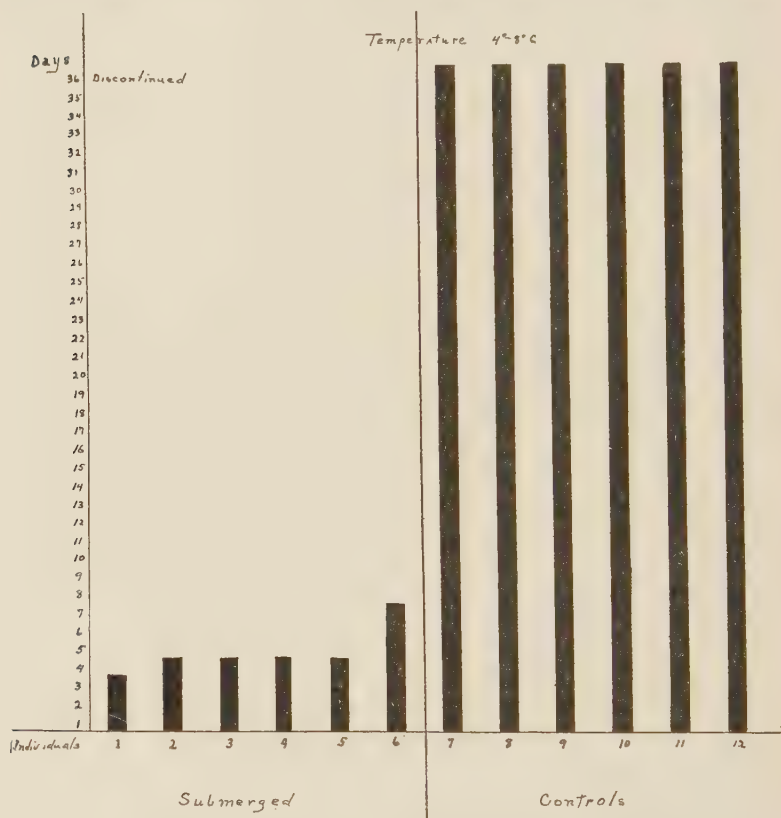


FIG. 42. Results of prolonged submergence experiment

day interval. When the temperature was raised to 12-15° C., they lived only 1 to 4 days. All the controls were alive 24 days later, when the experiment was discontinued. When the temperature was approximately 20° C., the submerged insects lived but 18 to 48 hours. Controls were alive 30 days later, when the ex-

periment was discontinued. From these results it would seem safe to say that the beetles do not receive enough oxygen from the water to support life even at low temperatures.

Surface visits

Since, therefore, the insects could not live when submerged for a long time they must come to the surface to renew the air supply and subsequent observations in the field confirmed this deduction. They were seen coming to the surface and diving at times when there were reasons to believe that it was their natural behavior. These visits were not frequent, even in small habitats where many beetles were present, but still this same situation prevailed in laboratory cultures, where the beetles had become adjusted. The reason for this infrequent surface relation will be explained under the topic "respiratory interval." The field observations are also substantiated by the evidence given under "mechanism."

MECHANISM

Experimental evidence

After it had been found that the beetles renew their oxygen supply by coming to the surface of water, it was important to know by what avenue the air was taken into the tracheae. According to other workers, as previously stated, it might be by way of the tip of the abdomen, or by way of the posterior coxal cavity. Therefore, in order to determine whether the beetles were able to live when permitted to take in air by one route only, some experiments were performed. Since in nature the beetles are at the surface for only a fraction of a second, it was necessary to provide the experimental beetles with the same brief interval if any conclusions were to be drawn as to the way they received their air supply. To accomplish this, the following apparatus (Fig. 43) was constructed. A stiff wire (*a*) with a semicircular bend in the middle was balanced on a standard, having a round, wooden plug (*b*) for a fulcrum. On one end of the beam was suspended an open vessel (*c*) containing an inverted U-tube (*d*). One arm (*e*) of the U-tube extended to the outside through a one-hole rubber

stopper in the bottom of the vessel, and the other did not quite touch the bottom. This was a special device for emptying this vessel of the water which had been led from a tap (f). None of the water that slowly dropped in could run out until its level had reached the bend in the U-tube. Then it would all be automatically siphoned out before stopping. By having the vessel filled and emptied at controlled intervals, that side of the beam would become alternately heavier and lighter, resulting in a fall and rise at regular periods. This device is a modification of the Scott-Johnstone siphon bucket. The other end of the beam was attached

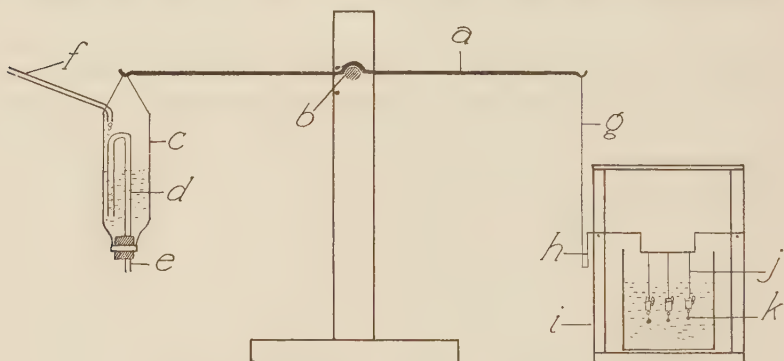


FIG. 43. Apparatus for rhythmical exposure of parts of the beetle to the atmosphere

by means of a cord (g) to the crank of a shaft (h), also made of wire. The shaft was supported by two vertical standards (i). Between the two supports the shaft had a square bend. To this were hung short pieces of wire (j) carrying beetles attached at the free end, on small strips of cork, which in turn were submerged in a battery-jar of suitable water. They were prevented from floating by means of a sinker (k). The beetles were fastened to the cork with very narrow strips of adhesive tape. The whole apparatus was adjusted so that, as the siphon bucket was being filled with water, the end of the beam on which it was suspended slowly dropped with corresponding rise of the other end. The latter lifted the crank, turned the shaft, and thereby brought the

beetles to the surface. The apparatus was timed in such a manner that the siphon bucket side of the beam was never down until it was completely filled. Then, as soon as a small amount of water had been siphoned off, the beam rose suddenly. This timing was necessary in order to make the duration interval of beetles at the surface as short as possible. The duration of the submergence interval could also be controlled and varied by allowing the water to enter the vessel at different rates. An additional feature was the fact that the apparatus would run day and night with only occasional attention to maintain the water at exactly the same level in the experimental jar. Also many individuals could be tested at the same time and all receive identical treatment. At first several beetles were attached to the cork so that only the tip of each abdomen extended above the water when raised to the surface. It was possible to do this because the coxal plates are shorter than the abdomen, and while the tip was exposed, the coxal plates were completely under water. Submergence intervals of ten minutes, thirty minutes and two hours were used. In experiments involving each of the intervals, the beetles were alive after two weeks of continuous trial. Other experiments already presented showed that they cannot do without air so long. The pygidium was observed to be extended into the air each time the beetle was at the surface and, if time permitted, extended and retracted several times. Since water prevented the entrance of any air except by way of the tip of the abdomen, it would seem that the experiment definitely proved that the beetles can live if they are permitted to obtain air only in this manner. No attempt was made to find the longest possible submergence period, since it had no bearing on this problem. Later, beetles were fastened to the apparatus in such a manner that the coxal plates were exposed to the air when raised. At the same time, the pygidium was prevented from being extended by means of strips of adhesive tape over the tip. The same results were obtained as in the first case. Therefore, it can be said from this series of experiments that the beetles are able to obtain air by way of either the tip of the abdomen or the posterior coxal cavity.

Photographic evidence

Though close observations under the binocular microscope showed that the beetles broke the surface film with only the tip of the abdomen, nevertheless, there was a possibility that all was not seen, since the duration of this process is very slight. For that reason motion pictures of the beetles coming to the surface and diving were taken through the side of the glass vessel. In every case the pictures showed only the tip of the abdomen in contact with the air, and the body was not extended far enough to expose the coxal cavity.

FUNCTION OF AIR STORE

It is a very noticeable fact that the beetles when submerged have a large bubble extending from the posterior coxal cavity. Its function has never been definitely established. As stated above, Brocher believed it to be of hydrostatic function only. Falkenström, although he does not mention the hydrostatic function, adds the idea that it acts as a diffusion membrane and takes in enough oxygen to allow the beetle to live indefinitely submerged, which has already been shown to be wrong. In addition, there is the problem whether or not the bubble is a true air store.

Hydrostatic function

The beetle reaches the surface by passively floating up or by swimming, but in either case it breaks the surface film with the tip of the abdomen. Whenever the bubble is absent, the beetle is heavier than water and will sink. Then it can reach the surface only by swimming. Orientation is also disturbed, so that it can no longer break the surface film with the tip of the abdomen. The same thing is true when the free portions of the coxal plates are removed. The clipping of the plates caused some difficulty at first, but with a specially devised instrument it was easily done. One tine of a pair of forceps was sharpened to a square edge and bent inward about one half of a centimeter from the end. The other tine was also ground down to a fine, square edge and

shortened so that the two tips of the tines just met. By slipping the straight tine under the coxal plate and pressing down with the other the coxal plate was easily clipped off in bits. As little or as much of the coxal plate could be removed as was desired. In fact, all traces of the free portions could be removed. In order to perform this operation the beetle was held fast by gently pushing its dorsal side down upon adhesive tape. Then it was removed to the stage of a binocular microscope, and the tape was held in position by means of the stage clips. When a beetle with the free portion of the posterior coxal plate removed is submerged in water, the bubble is no longer present and the beetle's behavior is similar to that of one robbed of its air bubble. Its equilibrium is likewise disturbed and it has to reach the surface by swimming. Also, it no longer breaks the surface film with the tip of its abdomen, but must crawl out if it is to renew the air supply. It would naturally seem that the bubble which the beetle has between the posterior coxal plates and the abdomen helps it to reach the surface and so orients the body that the tip of the abdomen can properly break the surface film. It likewise gives some hint as to the function of these greatly expanded posterior coxal plates that characterize this family of beetles.

Respiratory function

In order to find out whether the oxygen of the air bubble is used during its stay under water, an analysis was made by means of a modified Krogh's micro-gas analytical method (1908, pp. 279-288). A description of the apparatus (Fig. 44) and methods used does not seem necessary, since they were very similar to those of Krogh, which are well described elsewhere. However, a method of collecting the gas had to be devised. It was ultimately found possible to collect the very small bubble with a long flexible, glass capillary tube (*a*). The suction was applied by means of a column of mercury (*b*). When the gas for analysis was being collected, the free end of the capillary tube was placed in the water and allowed to become filled by lowering the column of mercury. Then the free end of the capillary tube was brought into contact with the bubble and part or all was drawn into it, followed by some more

water. Before the bubble reached the end of the capillary tube the column of mercury was raised and the bubble was transferred to the collecting funnel of the analyzer. Care was taken to prevent the bubble from being brought into contact with the air and to see that the apparatus was filled with the same kind of water as was in the cultures. The bubble could be removed repeatedly without disturbing the beetle. The time was noted when the beetle came

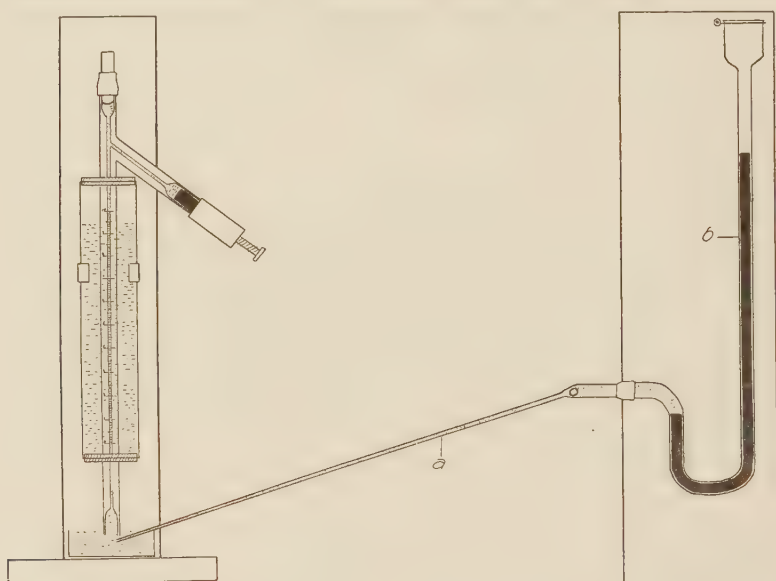


FIG. 44. Apparatus for analysis of micro-gas

to the surface and when the bubble was removed. The following are a few of the many records taken. Results of analyses are expressed in terms of percentage of the whole bubble volume.

These percentages are corrected for temperature. It is quite impossible to give another explanation of these analyses than this — that the animal during its stay in the water inspires and expires from and into the bubble in the posterior coxal cavity. Therefore, the air store is utilized during its stay under water. The behavior of the beetle greatly affected the percentage of oxygen present. If it had been swimming about very much before the bubble was

TABLE I
ANALYSES OF AIR STORES

Species	Time of analysis	O ₂	CO ₂
<i>Peltodytes edentulus</i> Lec.	Immediately after diving	19.1	0.8
<i>Haliphus triopsis</i> Say.	Immediately after diving	15.3	0.4
<i>Peltodytes edentulus</i> Lec.	Five minutes after diving. Active	10.2	1.4
<i>Peltodytes edentulus</i> Lec.	Ten minutes after diving. Active	5.5	2.3

taken, the percentage of oxygen decreased very rapidly. If it had been quiet previous to taking the bubble, the percentage of oxygen was much higher. These things have to be taken into account in order to get a clear understanding of what becomes of the oxygen.

Respiratory movements

If the oxygen of the air store was used by the beetles, there should be respiratory movements under water. As regards this, the author believes he has proof that such movements occur. After careful observations under the binocular microscope, the attached bubble was seen to become smaller and larger at rhythmic intervals. This change in volume of the bubble is interpreted as a sign of respiratory movements. Reasons for this statement are as follows. On examining a beetle out of water, with its elytra removed, there are very evident movements of the dorsum that would be taken as respiratory movements from what is known about other insects. Such movements under water would cause the bubble to become smaller and larger, as was observed. With the contraction of the dorsum, the space under the elytra would become larger and the air in the bubble would come in to fill it. On expansion of the dorsum the space would become smaller and then the air would be forced out. Since the beetles were at rest when observed, no other explanation can be given for this noticeable change in volume that occurs in the bubble.

Respiratory interval

When beetles are first put into the aquaria, they are always quite active and come to the surface very frequently. The same thing is true when they are disturbed, after they have become adjusted to an aquarium, or to natural conditions. It is very obvious that increased activity on the part of beetles requires more oxygen and therefore more frequent trips to the surface are necessary to supply this need. The duration of the submergence intervals of a disturbed beetle varies irregularly from two to three seconds to several minutes. On examining good cultures, however, a very noticeable difference is observed from what has been previously stated. The beetles are not very active, but move occasionally about the vegetation, now and then swimming short distances. When the proper precaution was taken, some were observed to remain submerged continuously for more than two hours. No attempt was made to find the longest period that an individual would remain submerged when not disturbed. It would seem from these two contrasting observations that these insects ordinarily use little oxygen and, therefore, frequent trips are not necessary to supply their needs. When they are disturbed and swimming about, the oxygen need is much greater and the submergence interval is, therefore, shorter.

SUMMARY

1. The imagoes of the Haliplidae must come to the surface of the water for their air supply even when the temperature is about zero Centigrade.
2. Normally, they take in air by way of the tip of the abdomen, although they can live if permitted to obtain the air only by way of the posterior coxal plates.
3. The air store retained by the posterior coxal plates has both respiratory and hydrostatic functions.
4. The duration of the submerged interval is dependent upon the nature of their activity.

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CONTRIBUTION TO THE BIOLOGY OF THE HALIPLIDÆ (COLEOPTERA).*

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The literature contains several scattered references to the biology of Haliplidæ. Except for the work of Matheson (1912, 156-193) and Wilson (1923, 231-345) on a few species, no extensive study of these beetles in America has been made. In connection with some life history (Hickman, 1930, 399-424) and experimental work (Hickman, in press) on haliplids, data were accumulated which seem worthy of publication. The beetles studied were found in the vicinity of Ann Arbor and of Douglas Lake, Michigan. In order to work out the life histories, it was necessary to develop culture methods by which the development could be carried through from the egg to imago. Such methods were discovered and the complete life cycles of all species known in Michigan were worked out.

The author wishes to express his indebtedness to Professor Paul S. Welch, under whose direction this study was made; to Professor George R. LaRue, director of the University of Michigan Biological Station, for the courtesies extended while working in the Douglas Lake region; and to various other persons for materials and assistance.

REARING METHODS.

The problem was first attacked by trying to keep the adults in the laboratory until egg laying time. After considerable experimentation, methods were found by means of which it was possible to maintain these insects the year around. Beetles collected in the field were separated, according to species, into finger bowls containing water, but not more than a dozen individuals were put in one bowl. Cistern water was used for the cultures of all the stages, although from experiments it appeared to have no particular advantage over tap, pond or distilled water. A little muck was placed in the bottom of

*Contribution from the Zoological Laboratory and the Biological Station of the University of Michigan.

the bowls in order that the beetles might hide in it when disturbed. Branches of *Elodea*, *Chara*, or *Ceratophyllum* were also introduced so that they could have a place on which to oviposit. The plants mentioned were never changed during the winter. Water was added about every month to replace that which had evaporated. During the summer, changes were made whenever the water became foul, at times as often as once a week. Temperatures up to about 75° F. had no detrimental effects, winter or summer, but much higher temperatures were destructive. Food was furnished not oftener than once a month during the winter since the beetles require little at this season, and the food will remain in good condition for a long time. During the summer, these conditions are reversed. The beetles require more food because they are more active and the food will soon deteriorate in warm water. As often as every other day a little food was added. The kinds of food will be discussed under a later topic.

When eggs appeared, they generally were removed to separate finger bowls which contained water. Removing the eggs from the water did not seem to do any damage. The temperature was maintained at about 70° F. No particular attention was given them until hatching time. Very few eggs failed to hatch.

The larvæ were very easy to rear in the laboratory when a few essential factors remained about constant, such as food, temperature, and condition of the water. They were separated into stender dishes which contained water to a depth of about one inch. Each larva was isolated in a dish. During the warm days of summer when the temperature was much above 75° F., the water was changed daily and all unconsumed food removed. The water was either removed by means of a large pipette or the larvæ were removed to new cultures by use of forceps. In order that the condition of the cultures dishes could be observed easily, they were arranged on a shelf one row deep. Covers were placed on the dishes to check the evaporation of the water. They were never exposed to the direct sunlight.

The pupa was the most difficult stage to obtain because the larva will not pupate unless conditions are right. Instead, it would remain as larva or would die. Nevertheless, the pupæ of all the different species were secured. When the larvæ

had reached the third instar they were transferred to a smaller stender dish containing a little water and food. A branch of water plant was so arranged that it extended over the top of the dish in order that the larvæ could crawl out to pupate. This small dish was placed inside of a larger stender dish which contained a small amount of earth. This earth had been taken from the shore of the lake in the vicinity of the place where they naturally would pupate. Before they would enter this earth the latter had to have the right moisture content. This seems to be the most important factor. If it was too wet or too dry they would not construct the pupa chamber. It was found that if the earth was just damp enough to hold together, the larvæ would pupate. A few drops of water were added from time to time to prevent undue drying. Fungus growths had to be watched for and eliminated. They were largely avoided at the outset by moistening rather large quantities of this shore material, allowing it to stand for a few days before using, and selecting those samples which showed no fungus growth.

BIOLOGY OF THE IMAGO.

Although the general environment of these beetles has been known for a long time, yet, it seems proper to analyze the habitats a little more in detail. Generally speaking, adult haliplids are found in standing water or slow streams where the proper food is found. They are not adapted to swift currents, as they can not swim fast enough to make any headway. The habitats might be enumerated as follows: pools; deep, slow moving streams, protected places along rivers; roadside pools; ponds; and protected places in lakes. In fact, they were always found where their food occurred, and since all of the different kinds of food are not found in all the places mentioned above, there would necessarily be a limitation as to which species might be present. Within the usual limits, such factors as pH, dissolved oxygen, and transparency seem to have no effect on the distribution. *H. immaculicollis* Harr. was more generally found in the smaller ponds and pools. *H. cribrarius* Lec. occurred only in the slightly deeper water of lakes among the *Chara* and *Nitella* beds, and was the hardest to collect for this reason. Some were taken under 6 feet of water, and they might have been taken in still deeper water had the special

effort been made. *II. triopsis* Say is another lake form found among the *Elodea* and *Chara*, but was taken often near the shore in shallower water. *Peltodytes sexmaculatus* Rbts., and *P. edentulus* Lec. were cosmopolitan in distribution as they were found in all the above listed places. In the vicinity of Ann Arbor, *P. lengi* Rbts. is restricted to the Huron River and its branches, although no reason can be given for this selected habitat.

Matheson (1912, pp. 181-182) and Leng (1913, p. 33) have discussed the structural adaptations of these beetles for aquatic life and further comment seems unnecessary except to mention another function for the posterior coxal plates. It has been already stated by many investigators that these plates retain an air store but experiments discussed in another paper (Hickman, in press) showed that the expanded coxal plates enable the beetle to hold a bubble of air for the purpose of tipping the apex of the abdomen through the surface film.

Not much can be added to what is already known concerning the locomotion of these beetles. They are poor swimmers although the tarsi of the second and third legs are provided with a fringe of long setæ. That they swim with ambulatory movements was definitely proven by means of motion pictures. They spend most of their time while in water walking over the vegetation and swimming short distances. On land, they are good walkers and can run with some speed. They can fly as shown by the fact that they have been taken at electric lights (Knaus, 1899, p. 110). In the laboratory, they very often will leave the cultures and fly to a desk light.

Several investigators have observed that the beetles of this family are not carnivorous as was generally thought, but are herbivorous. Matheson (1912, p. 182) was the first to observe that they feed upon plants. He states "In my aquarium *H. ruficollis*, *H. connexus* and *H. cribrarius* were observed feeding greedily on the contents of *Nitella*, the softer portions of *Chara* and other filamentous algæ." Some years later, Pearce, (1921, p. 184) in speaking of the food habits of *Haliplus*, writes "In each case the specimens fed happily on the algæ, and were not observed seeking for animal food." Wilson (1923, p. 273) makes a rather definite statement about the food habits of *Peltodytes edentulus* Lec., "as far as observed they feed entirely upon *Chara* and *Nitella*" and also the same kind of statement

for *H. ruficollis* DeG. "They feed exclusively upon filamentous algæ." Falkenström (1926, p. 15) reached the same conclusion "Infolgedessen glaube ich feststellen zu können, dass nicht nur *H. immaculatus*, sondern auch mehrere andere Haliplidenarten, wenn nicht alle, Algenfresser sind, und dass sie nur in Ermangelung der Algen oder vielleicht anderer geeigneter Wassergewächse bei stürkerem Hunger animalische Nahrung ergreifen." The author's observations and results of various tests are in agreement in part with the above statements. Since the beetles will live a long time without apparent food, the problem was a very difficult one to solve. Records were obtained which showed that the beetles lived as long as a month and one-half in filtered, cistern water. Nothing was unusual about the habits of the beetles during the starving period up to a few days before death. So it was difficult to determine when they were receiving the proper nourishment. Great numbers were lost at first because from their behavior it was taken for granted they were getting the proper food. This seems to have been the same error made by other investigators. By means of an elimination test certain facts were obtained for the different species. Various kinds and combinations of aquatic plants and animals were tried. Such plants as *Spirogyra*, *Elodea*, *Chara*, *Nitella*, *Ceratophyllum*, *Lemna*, *Juncus*, *Ulothrix*, and unicellar algæ were used. Animals such as *Tubifex*, snails, Entomostraca, fresh beef, various insect larvæ, and dead beetles of the same family were also offered to the beetles as possible food. Although, when starved for a few days, they would attack and eat animal substances, but they were not kept alive very long on that kind of a diet.

Spirogyra proved to be the only kind of food that gave satisfactory results for four species, *Peltodytes edentulus* Lec., *P. sexmaculatus* Rbts., *P. lengi* and *Haliplus immaculicollis* Harr. Beetles of these species have now been kept living on this kind of food for eighteen months. During this time, they have laid eggs that hatched. *Nitella* was the only food that gave successful results for *Haliplus cribrarius* Lec., and *H. triopsis* Say. They have been kept alive for about nine months. The possibility that, in nature, other substances may be taken as food, is not necessarily ruled out, but satisfactory results have thus been obtained in the laboratory. With these things in mind it can be said that the beetles of the species studied are herbivorous and feed upon algæ.

No definite figures are known for the length of life of these beetles. The author kept beetles alive for eighteen months and they were still alive when the culture had to be discontinued. They were the first to be successfully cultured in the laboratory.

It was generally inferred that the beetles hibernate during the winter months, probably because they had never been collected. The author has collected them under 22 inches of ice, which had been on the lake for 3 months. The beetles were actively swimming about. While collecting through a hole in the ice individuals appeared at the surface and then dived. From the manner in which they came to the surface, it was decided that they must have had a bubble of air attached to the coxal cavity, otherwise, their behavior would have been entirely abnormal as has been shown in a previous paper (Hickman, in press). The question as to where they get the oxygen necessary for their activities during the winter has never been satisfactorily answered. Several theories have been advanced. Scott (1910, pp. 35-36) thinks that the filamentous algæ produce oxygen and that the *Typha* stems allow some gaseous exchange with the atmosphere. Wesenberg-Lund (1913, pp. 44-45) states that the aquatic beetles will collect in places where there are many green water plants and that they make use of the oxygen given off from them. The author's collecting experiences confirm Wesenberg-Lund's statement of the beetles' congregation at places where there are numerous green aquatic plants. Some of the largest collections made at one time were secured at such a place in the month of December. For example, during the past two winters, the beetles have been taken in numbers very much greater than during the summer at a patch of *Juncus* (bog-rush). Whether there is any connection between this particular water plant and the over-wintering of the beetle is not known. They are, however, very resistant to freezing, as tests in the laboratory show that they can be frozen solid in ice and still live. One test showed that beetles alternately frozen during the night and thawed out during the day over a period of twelve days were still alive. How long they could endure freezing is not known.

These beetles are not fast swimmers, a fact that Matheson (1912, p. 182) has already stated. "The swimming efficiency is very feeble as compared with the more specialized Dytiscidæ.

Instead of a soldering fast of the posterior coxæ and the formation of a solid joint, as in the Dytiscidæ, there is a remarkable plate-like development of the coxæ. By this means the hind legs are moved in one plane and their efficiency as swimming organs increased though their horizontal range of movement is, if anything, lessened." They will go to cover when disturbed and dig under the leaves or muck until they are hidden. Also they spend most of their time walking about over the vegetation rather than swimming. In this way they are not very noticeable and their larger enemies probably have more difficulty in finding them than if they were in open water. They have the death feigning habit and will remain motionless for a period of from a few seconds to several minutes when touched. This is a very good protective habit when out of the water as they sometimes are.

As early as 1880, Forbes recorded that *Haliplus* was eaten by *Semotilus corporalis* Mitch., the eastern chub. McAtee (1918) found beetles of this family in the stomachs of three species of Mallard ducks. Mabbott (1920) states these beetles were common in the stomachs of seven species of shoal ducks. No great amount of work was done on this subject but a few observations were made. The stomach contents of a sunfish taken at Douglas Lake included the elytra of a *Peltodytes* species. In the laboratory, they were eaten by frogs, *Dytiscus* adults and larvæ, and dragon-fly naiads. So it seems that most any aquatic insect eater might prey upon them.

In the course of dissecting some of these beetles there was found a stage of a water mite (*Hydracarina*) attached to the under side of the elytra. Pearce (1922, p. 37) had noticed the same for *Haliplus obliquus* Er. The author found them only in *Peltodytes edentulus* Lec., and *P. sexmaculatus* Rbts. The material was sent to Dr. Ruth Marshall, who identified and reported them (1927, p. 270) as the nymphal stage of *Eylais desecta* Koen. These water mites apparently do not seriously harm the beetles, as infested individuals isolated in November, 1926, are still alive (April, 1928). During the summer of 1927, these infested individuals laid eggs in the usual way. It seems likely that if the infestation be great they might interfere with the natural respiratory movements. Generally there is only one mite to a beetle but as many as six per host have been found.

The only record of copulation is that of Matheson (1912, p. 183, 186). He states that copulation takes place during the latter part of April and the month of May and that egg laying begins shortly afterwards. The author observed copulation in *Peltodytes edentulus* Lec., and *P. lengi* Rbts. in the last week of April and egg laying occurred one to two weeks later. Yet, a female beetle isolated in a culture in November of the previous year laid eggs about the 15th of May and normal larvæ hatched from them. It would thus seem that copulation took place as early as the fall before. Also copulation was noticed in the aquarium during the month of August for *H. immaculicollis* Harr. Still no eggs were laid in the culture that fall. More data are needed to clear up this point.

EGG-LAYING HABITS.

The period of egg-laying is very definite for the months of May, June and early part of July. There may be another one in the fall months as will be shown later in the discussion of the life cycle.

The number of eggs deposited by one individual varied from 30 to 40 but it was very hard to get a good count as they are not all laid at one time, but scattered over the period of a week or more. The time of laying varied greatly with different individuals. In a culture containing several females, eggs were collected from May first to July fifteenth and then only a few at a time.

The places where the eggs are laid are identical for the three *Peltodytes* species. They are laid on aquatic plants such as *Elodea*, *Ceratophyllum* and filamentous algæ. The previous statements are based upon field observations. In the cultures, they were laid on various things that might be in the aquarium. In several instances they were found on the long projections of *Peltodytes* larvæ which happened to be in the cultures with imagoes. There seemed to be no correlation of place of deposition with depth of water. Some were near the top and others under several inches of water. They were glued on one side to supporting objects but in no regular manner. *Haliplus immaculicollis* Harr. laid its eggs in holes which it cut in the stems of *Ceratophyllum*.

The process of egg-laying was observed but once and that for *Peltodytes lengi* Rbts. The female hunted around over the

branches until a suitable place was found and then deposited an egg. Actual laying required only a few seconds. Then the female moved a little and deposited another one. There seemed to be a sticky substance on the egg when first deposited which held the egg fast to the stem. This substance was all over the egg as instances were found where it was glued to more than one branch.

The chorion is sufficiently transparent to allow observations on development. After about 5 days, the six ocelli were observed as dark pigment bodies on each side of the egg. This fact was also observed by Falkenström (1926, p. 20). A few days later, faint outlines of body structure appeared. The larva lay on its back in the egg and the anterior and posterior ends were folded back upon the ventral surface. Body structures became more distinct up to the time of hatching and served as an indication of the hatching time, which took place about 8 to 10 days after oviposition.

The larva broke out slowly through a longitudinal slit which extended over the anterior end and more than half-way down each side of the egg. Those observed required about 3 hours from the beginning of hatching until they were free.

HABITS OF THE LARVA.

Larvæ of *P. edentulus* Lec., *P. sexmaculatus* Rbts., *P. lengi* Rbts. and *H. immaculicollis* Harr. were found among masses of filamentous algæ. At times they also occurred where no algæ were present, but this could be understood from the behavior of the algæ. Filamentous algæ, especially *Spirogyra*, are rather fast in growth and also fast in disappearance. Therefore on one date there might be a lot of the algæ at a particular spot and a few days later apparently none. Larvæ of *Haliplus cribrarius* Lec., and *H. triopsis* Say were taken only in *Chara* and *Nitella* beds and were therefore more restricted in habitat.

The larvæ are adapted only for crawling, and are very slow in their movements. Instead of hastening away when disturbed they will curl up and remain so for some time (3 to 6 minutes). They can not float but must reach the surface or shore by crawling over the vegetation or bottom.

The food without a doubt is algæ. The species of *Peltodytes* and *Haliplus immaculicollis* feed exclusively on filamentous algæ. The first pair of legs are particularly adapted for this

kind of food. By means of these legs they grasp the filament, pass it back in a hand-over-hand fashion until they reach the end. Then, they push it forward, at the same time puncturing each cell and sucking out the contents. They are very rapid feeders, and consume great quantities of algæ, especially when the larvæ are in the first and second instars. *Haliphus cribrarius* Lec., and *H. triopsis* Say feed upon *Chara* and *Nitella*, although in an entirely different manner. Their first pairs of legs are not adapted for grasping and passing the food to the mandibles as was previously stated for the filamentous algæ feeders. In fact, since *Chara* and *Nitella* are attached plants, they could not be so handled. Instead, the larvæ, after selecting a place to feed, scrape off the outside layer of the branches with the mandibles by means of a downward movement of the head, at the same time drawing in the loosened material through the suction canals. They usually begin to feed anywhere on the branches and make no effort to remove all of the layer but only in patches. Any slight disturbance in the cultures will stop them from feeding and many seconds usually elapse before beginning again.

The first and second larval instars are without spiracles so they must receive their oxygen by cutaneous respiration. The third larval instar of all the species studied has open spiracles and those of *Peltodytes* have the tracheæ extending out into the long body projections. These projections can be clipped off and still the larvæ will pupate. For that reason they must not be of vital importance. The third larval instar of *Peltodytes* species was thought not to have spiracles, but Steinke (1919, pp. 10-11) found them and the author has confirmed his results.

Only inferences can be stated about their protection. Presumably, the filamentous algæ feeders receive some protection by living on and within the algæ masses. They are not readily seen and their enemies are perhaps hindered by the strands from moving readily in search of these larvæ.

The *Chara* and *Nitella* feeders, it would seem, are protected from enemies by coloration and body forms, which are very similar to that of the plants. Also they are not easily detected by their movements as they are very slow crawlers.

Three instars are typical for beetle larvæ and it is very easy to distinguish them because the body projections become more complex for each instar. Head dimensions and total lengths

also are very dependable as characters for separating the instars.

Ecdysis was similar to that of other aquatic larvæ. A break in the skin occurred along the epicranial suture and extended posteriorly through the mid-dorsal line of the prothorax, mesothorax and metathorax. The process was very slow and required about two hours.

Generally speaking, of the beetles reared in the laboratory, the first larval stadium lasted about 5 to 7 days; second, 6 to 8 days, and third, 5 to 10 days. Very few larvæ died in the cultures even during the difficult and critical process of ecdysis which is some indication that the stadia were of normal duration. The last larval stadium may be much longer if conditions are not optimum for pupation. Many things prolonged these periods, such as starvation and low temperature. These stadia were about the same as reported by Matheson (1912, pp. 183-187).

Larvæ of the genus *Haliplus* were collected during the winter months and since the larvæ of all Michigan species were kept alive in the laboratory until February or later, it would seem that they will pass the winter in active form if conditions prevent them from pupating before cold weather appears. On December 19, 1927, larvæ of the second and third instars were taken under the ice at Geddes Pond. Second instar larvæ had not changed to the third larval instar as late as April 13, 1928, although they were kept in the laboratory at room temperature. Falkenström (1926, p. 12) states that for the most part they spend the winter above the water. The author's results do not confirm this statement.

The greatest enemy is probably fish, especially the minnows that live around among the algæ where the larval period of the beetle is spent. Wilson (1923, p. 260) gave evidence for this statement. Other things have attacked them in the laboratory, such as carnivorous insect larvæ and frogs. This suggests that possibly they are likewise enemies in nature. Various mites, crustaceans, and other organisms run over them, although no great harm was ever done in the cultures. In summer, enchytraeids were often wrapped around the larvæ, but there was no sign of resulting harm. On the whole, they were rather resistant to the smaller enemies. One added advantage is the fact that the larvæ are free from cannibalism and any number can be kept together.

A few days after the third larval instar was formed the larvæ began to wander about the culture apparently trying to get out. When allowed to get to shore material, they began to select the proper place in which to dig. After burrowing below the surface, up to a depth of one inch, they made a round cavity by digging the earth away and trampling it down. It required from one to three days to construct the chamber. After finishing the cell they curled up in the form of a semi-circle with the dorsal side resting on the floor of the cell and remained in this position for 2 to 4 days previous to pupation.

THE PUPA.

The pupal period was 12 to 14 days. Although the pupa was completely buried and was in the dark, these conditions were not necessary for its development. Some of the cells were uncovered and exposed to light, yet the pupæ transformed normally.

Several times a cell was uncovered at the time of transformation. The pupa is a typical exarate type and the process of changing to adult is very similar to other beetles. Time required by the pupa to shed the exuvia is about twelve hours from the first apparent sign of activity to the end of process.

LIFE CYCLE.

It has been definitely proven from cultures and field collections that there is a summer generation which includes the months of May, June, July and the first part of August for all the species studied and there are indications of another generation that begins in the fall and extends over to spring. For the summer generation, eggs are more numerous during the first part of May but may be found as late as the middle of July. Larvæ appear after about eight days and remain in the water at this stage for about three weeks including all instars. Then the larvæ seek the shore to pupate. The interval required from the time the larvæ enter the ground to their emergence is about two weeks. The imagoes seek the water immediately after leaving the pupa chambers. This whole period from egg to adult is about six weeks.

There may be another fall generation from the fact that larvæ of the second instar were collected in December and remained as such in the laboratory until the following April.

Summer collecting gave no indication that the earlier instars would remain that long. It was noticed while collecting at a particular spot that on one occasion a great majority of larvæ were taken in the first instar. A few days later, the greatest number were larvæ of the second instar and still a few days later the larvæ were almost all third instars with a few second and no first instars. It seems that this is a check on the data from laboratory cultures. However, the larvæ on the first and second instars never prolonged their period even when food was scarce, but the third instar will continue as such if not given a chance to pupate. The larvæ of the second instar, collected in December, were kept under the same conditions as the summer larvæ, yet the stadia were prolonged. Why was it prolonged in the winter and not in summer? The answer is not known but it would seem that it was due to something within the larva and not to outside factors.

Falkenström (1926, p. 13), unsuccessful in having the larvæ pupate under laboratory conditions, came to the conclusion that they do not naturally pupate during the same summer in which they are hatched. He states: "Die Larven erreichen während des Sommers ihres Ausschlüpfens nicht die Reife, um die Metamorphose durchmachen zu können, sondern überwintern als Larven in verschiedenen Stadien."

As already indicated, the author's findings are entirely different from those of Falkenström and confirm even more definitely the earlier proposal of Matheson (1912, p. 191): "There is probably more than one brood a season."

It may be that Falkenström's difficulty in getting the larvæ to pupate was due to faulty culture methods, as the author has already stated that he himself experienced the same thing at first. However, when conditions were right the larvæ would pupate.

CONCLUSION.

1. Culture methods were developed for keeping the imagoes alive in the laboratory the year around, and for rearing these beetles from egg through all of the life history stages.

2. Imagoes and larvæ of the three species of *Peltodytes* and of *Haliplus immaculicollis* feed upon filamentous algæ, especially *Spirogyra*. *H. cribrarius* and *H. triopsis* feed upon *Chara* and *Nitella* in both mature and immature stages.

3. There is definitely one generation in the summer, and evidence of a fall generation that extends over to the following spring.

4. Both imagoes and larvæ spend the winter in the water, and manifest the same activities as during the summer.

5. The duration of the third larval instar can be prolonged for nine months or longer by keeping the larvæ in water and preventing them from reaching soil to pupate.

6. Nymphs of a water mite, *Eylais desecta* Koen, were found attached to the under side of the elytra of *Peltodytes edentulus* and *P. sexmaculatus*.

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